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Water Quality Inventory and Monitoring—Katmai National Park and Preserve

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Final Report to the National Park Service
Interagency Agreement IA 9700-0-9017
Work Order No. 15 of Unit Cooperative Agreement No. 14-16-0009-1532

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Executive Summary

Background

Limnological data were taken as supplemental information to studies of sockeye salmon in the 1950s through the 1970s that were conducted primarily on the four lowest altitude lakes in the Naknek drainage and the two lower headwater lakes of the Alagnak drainage. This study was conducted to begin to establish a baseline of the water quality of Katmai National Park and Preserve. This study emphasized conditions in the 10 largest lakes by sampling them once each summer from 1990-1992. Additionally, limited sampling was conducted on major inlets and outlets of these lakes, emphasizing the inlets of Brooks Lake which were sampled each of the 3 years. The lakes were accessed by floatplane, which was anchored at a single station in each. A profile of conditions was taken with a water quality multimeter, a light penetration profile was taken, the Secchi depth was measured, samples were taken for water chemistry analysis and algal biomass, and net hauls were made for zooplankton samples. Additionally, nutrient stimulation bioassay experiments were conducted on the phytoplankton of five lakes in 1992 and 1993. Standard methods or their accepted surrogates were used for all measurements. A complete program of quality assurance and quality control was utilized.

Major Findings

The lakes were found to be warm thereimictic, which means that they can circulate with the proper wind conditions at any time during the ice-free season. This type of lake contains more summer heat than similar lakes that stratify. The appropriate measurements showed these lakes to be oligotrophic or low in nutrients and resultant plant growth. Nevertheless, the

mixing conditions and heat allow these lakes to be important producers of fish, particularly juvenile sockeye salmon. The lakes were of various chemical types with the six high-altitude ones obviously acid sensitive. Battle Lake, which has the lowest alkalinity, also had elevated concentrations of aluminum. Because of the low algal and zooplankton concentrations of Battle Lake and the probably toxic levels of aluminum, it is doubtful that sockeye spawned in its inlets rear in Battle Lake. It is speculated that they rear in the next lake down, Kukaklek Lake.

These lakes are extremely clear except for the Iliuk Arm of Naknek Lake and the upper end of Kulik Lake, where glacial flour enters from inlets. Battle Lake has a similar light penetration coefficient to Crater Lake, Oregon—considered to be one of the clearest lakes in the world. Planktonic algal biomass was directly related to total phosphorus concentrations among these lakes, and the resultant water clarity, as measured by the Secchi disk, was found directly related to both total phosphorus and phytoplankton biomass. The empirical relationships were quite close to those published for a large data set of temperate lakes. Therefore, eutrophication of these lakes can be monitored by time-series measurements of Secchi transparency, which is easy to measure. The nutrient stimulation bioassays confirmed the nitrogen limitation of Brooks Lake published by Charles Goldman in 1960, who also found Becharof and Naknek lakes' phytoplankton to be nitrogen limited. Experiments found Coville Lake to also be nitrogen limited, but Grosvenor, Kulik, and probably Nonvianuk lakes were found to be phosphorus limited.

Zooplankton concentration was directly related to phytoplankton concentration among these lakes. Zooplankton biomass was lowest in 1991, probably due to the generally colder water temperatures that year.

For the lakes where all mapped inlets were sampled, lake concentrations were in the middle of the range of inlet concentrations. Three inlets of Battle Lake had no titrable alkalinity, and another had only 2% alkalinity (of the major anions). Chloride dominated most Battle Lake inlets except Iron Springs Creek, which was dominated by sulfate. Unusual inlets such as these may have an influence on the receiving lake, at least locally. High levels of aluminum that might be chronically toxic to aquatic organisms were found in Iron Springs Creek and in Up-a-Tree and Headwaters creeks, tributaries of Brooks Lake. Levels that could be acutely (lethally) toxic were measured in the Savanoski and Ukak rivers.

Management Implications

These pristine, clear lakes are national treasures and deserve the protection afforded by Park and Preserve status. The 11 largest lakes have great volumes and would probably only be affected by large urban development. However, careless waste disposal and land clearing activities could certainly have local, temporary effects on water transparency. Smaller lakes should be protected from receiving additional nitrogen and phosphorus by not allowing establishment of concessions that attract heavy visitation to their watersheds. Such concessions are more appropriately sited near the large lakes and streams.

The four large lakes of the Alagnak drainage and the two highest altitude lakes in the Naknek drainage are acid sensitive. Their airsheds should be protected from activities in their airsheds that would deposit acid precipitation. Activities of concern would include smelting of metal ores, power generation from fossil fuels, urban automobile exhaust, etc.

Mining for metals, particularly those associated with reduce sulfur minerals, must be prohibited in these acid-sensitive watersheds. Battle Lake

already receives acid-mine type drainage, which may be natural. Allowing additional acidity to enter Battle Lake might make the water even more transparent, but would probably harm the sockeye salmon runs to the inlets where they currently spawn.

The streams of Katmai National Park and Preserve, particularly the small ones, should be protected from activities such as logging, mining, and so on that would have known harmful effects on them or on receiving waterbodies. Park staff and visitors should be cautioned not to use the waters of the Battle Lake watershed or of the Savonoski or Ukak rivers as drinking water due to the possibility of high concentrations of toxic metals. Of course, visitors and staff should be informed of the dangers of drinking unfiltered or unboiled water from any surface source because of the danger of water-borne diseases and parasites.

Long-term Monitoring Strategy

The large lakes that are not yet bathymetrically mapped should be at least roughly mapped before further studies. GPS-fixed stations should be established in the deepest spot of major basins of each lake to be monitored. Monthly Secchi depth readings should be taken during the ice-free season and a seasonal average calculated. A steady, upward trend in summer average Secchi depth for a lake that continues for 5 or more years should signal possible eutrophication and the need for intensive limnological studies.

The largest streams in the Park and Preserve should be gaged in conjunction with the USGS. Flow data are needed for any stream where water quality characteristics are being measured. Streams that are used for drinking water by staff and visitors should be monitored, at least for comparison to the drinking water standards. These samples can be examined

in the same process as used for the public water supply wells in the Park and Preserve as proscribed by Alaska law.

Introduction

Early, limited limnological studies of Katmai National Park and Preserve waters were conducted incidentally to projects on fish [mostly sockeye salmon *Oncorhynchus nerka* (Walbaum)]. Starting in the 1950s, projects were conducted mainly by the Auke Bay Laboratory of the U.S. Bureau of Commercial Fisheries (later called the National Marine Fisheries Service). In the 1960s and since Alaska statehood (1959), studies were initiated by the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game as Federal Aid projects. In addition, several universities had individual students working on graduate degrees, and other agencies had short projects on occasion. Limnological data were published in a paper by Burgner et al. (1969) and selectively summarized in a report to the National Park Service by Buck et al. (1978).

An electronic literature search conducted in 1989, before this project began, did not recover any limnological data past 1977. In 1992, A. J. Gunther, a lichenologist, published a paper on the chemical limnology of the Alagnak and Naknek river systems, and in 1993, I (LaPerriere, 1993) published a paper responding to his paper and to some of the early Bureau of Commercial Fisheries data on the Naknek River system.

The fishery-related studies that were conducted on the Naknek system concentrated on the four lowest altitude lakes, and only the two lower lakes in the Alagnak system were additionally studied in the late 60s in Burgner et al. (1969). Gunther (1992) sampled large and small lakes in both watersheds, skipping over some of the major lakes. Particularly affecting some of his conclusions was the lack of samples from the largest lake, Naknek Lake.

Goldman (1960) studied the phytoplankton of Naknek and Brooks lakes, as well as of Becharof Lake, which is outside the present Park and Preserve. In all three lakes, he discovered the plankton algae to be nitrogen

limited regarding growth. He also found that because of reduced light penetration in Naknek Lake, it had less planktonic primary production per unit area than did Brooks Lake.

My study was designed to set a baseline for major and trace ions, including important plant nutrients, and to detect any signals of cultural eutrophication now, as compared to earlier studies.

The project objectives were to:

1. Inventory and classify aquatic environments by chemical and biological characteristics, documenting interannual variability;
2. Develop a baseline inventory of water quality characteristics important to aquatic life in major watersheds;
3. Ascertain (where possible) if water quality criteria have been met or exceeded; and
4. Identify and document the magnitude and direction of changes in the aquatic environments which have occurred in the last 30 years.

Study Area

The study area consisted of the 11 large lakes and some of the important inlet, outlet, and connecting streams along the Naknek and Alagnak drainages within Katmai National Park and Preserve (Figures 1–5). Only five of these lakes have been mapped for bottom contours, and all of those are in the Naknek drainage. The Naknek lakes range from 10 to 518 m in altitude and from 3 to 492 km^2 in area (Table 1). The Alagnak lakes all lie between 192 and 254 m, and vary from 13 to 177 km^2 (Table 1).

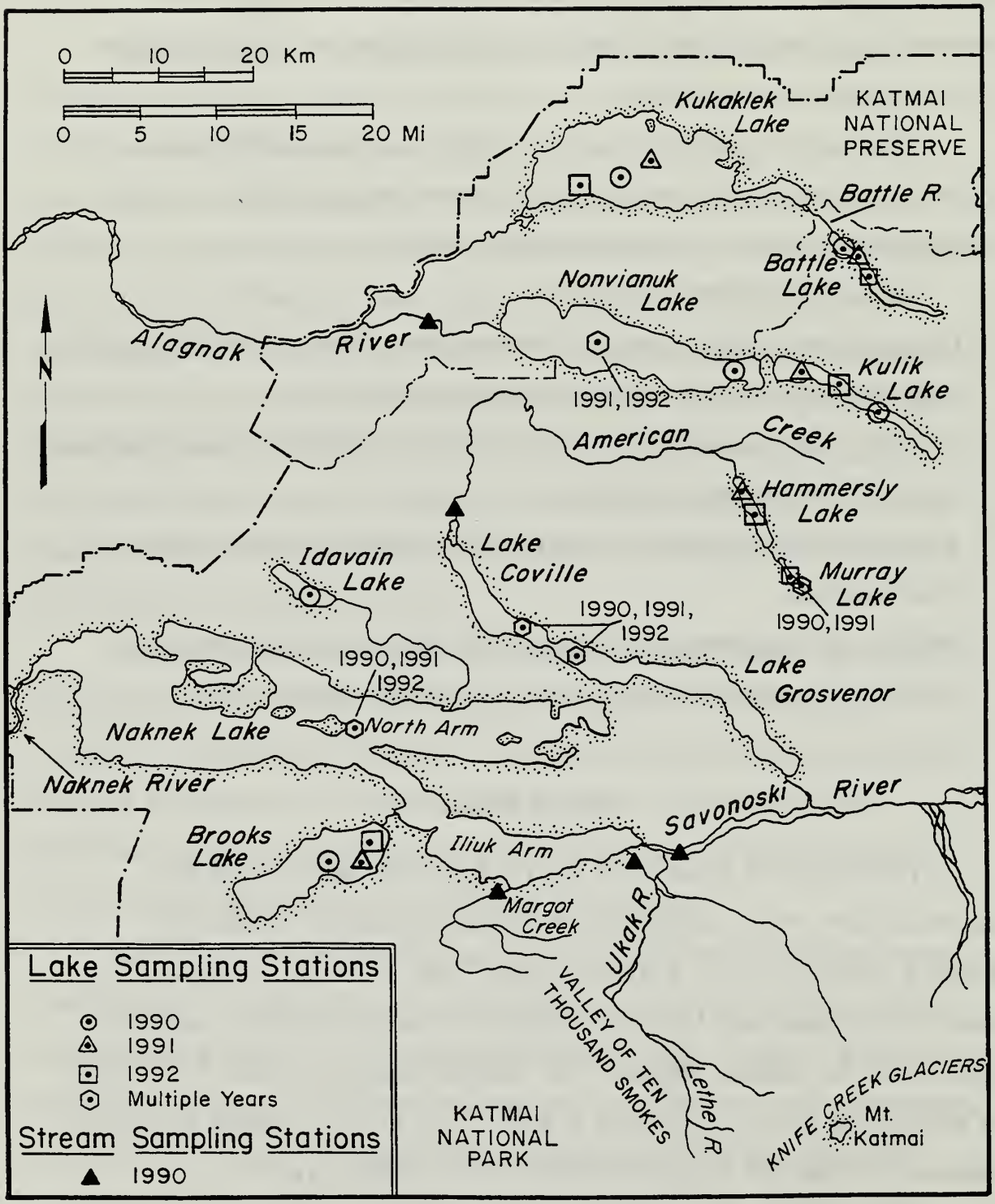

Figure 1. Lakes and large streams of Katmai National Park and Preserve sampled in the baseline water quality study.

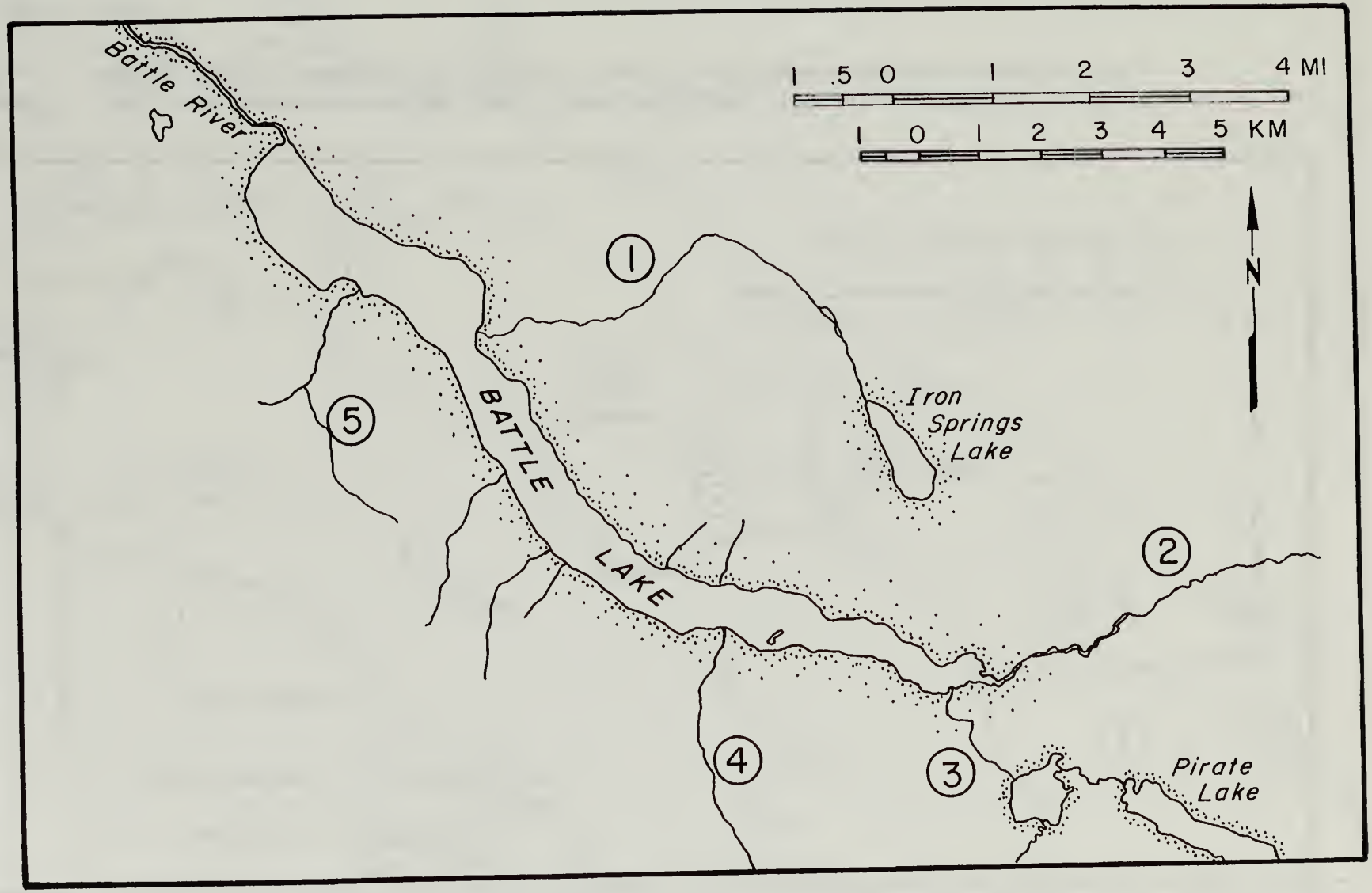

Figure 2. Battle Lake inlet streams sampled 1990.

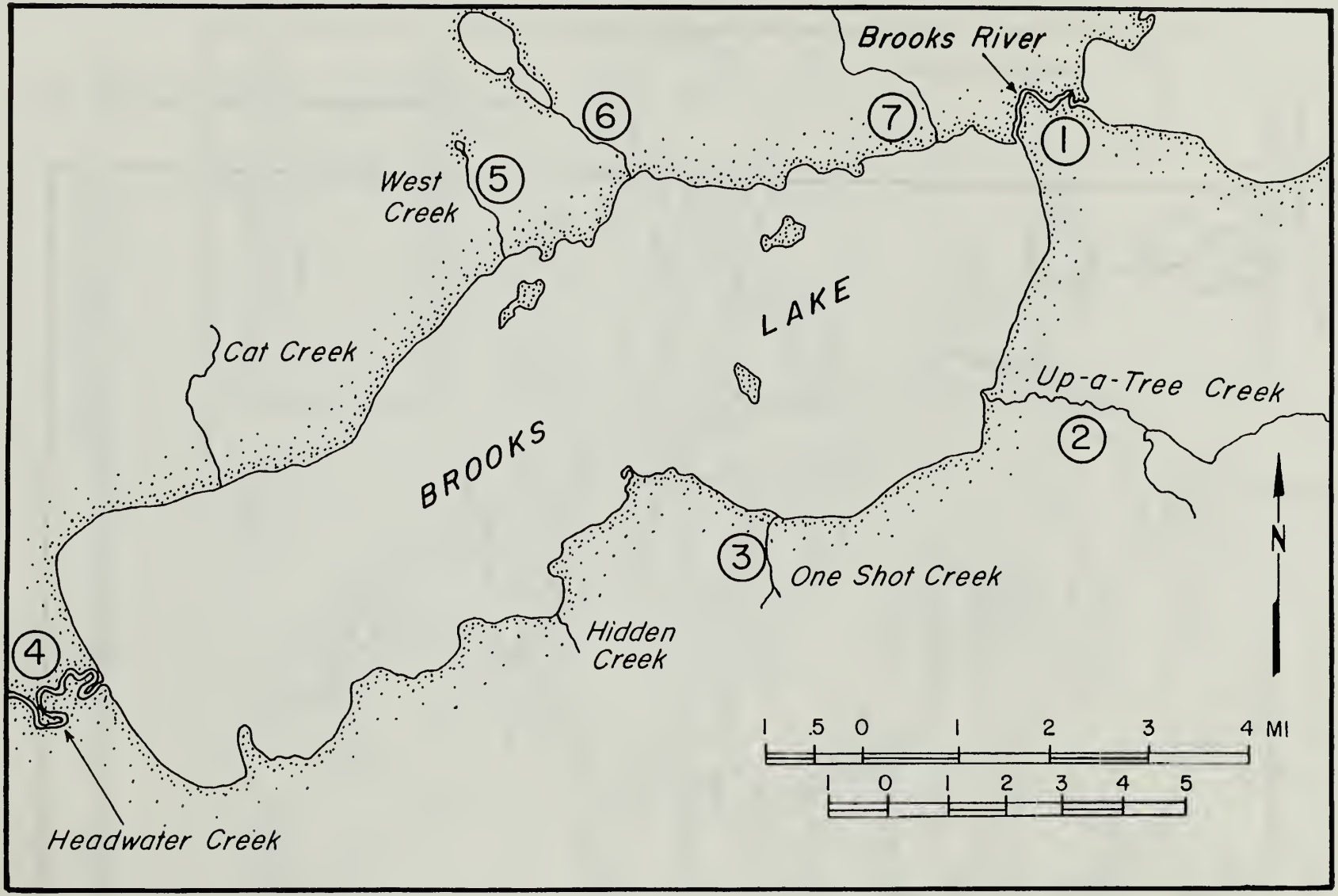

Figure 3. Brooks Lake inlet streams sampled 1990–92. (Stations sampled in 1990 are numbered within circles. Stations 2–5 and Hidden Creek were sampled in 1991. Stations 2–4 and Cat and Hidden creeks were sampled in 1992.)

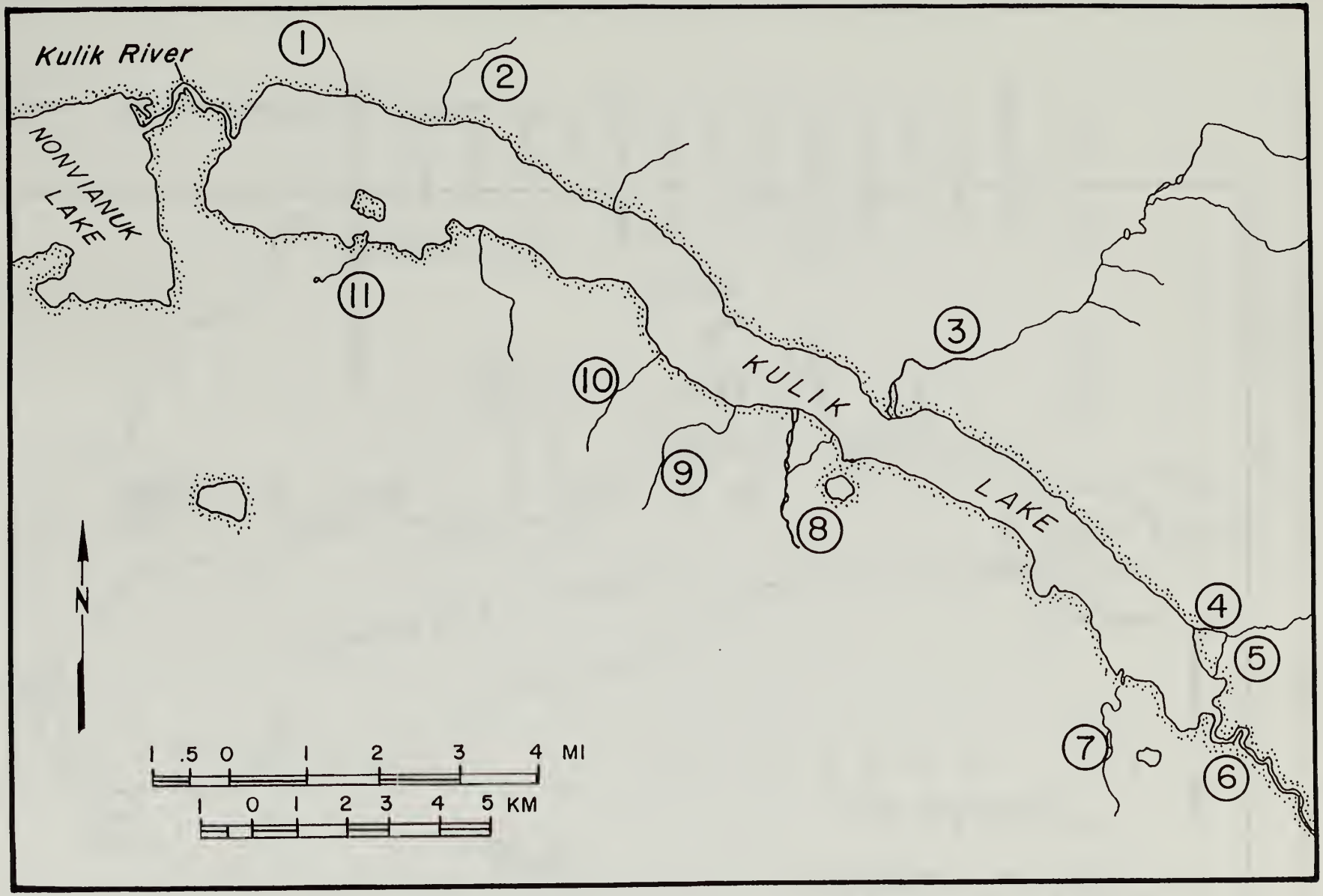

Figure 4. Kulik Lake inlet streams sampled 1992.

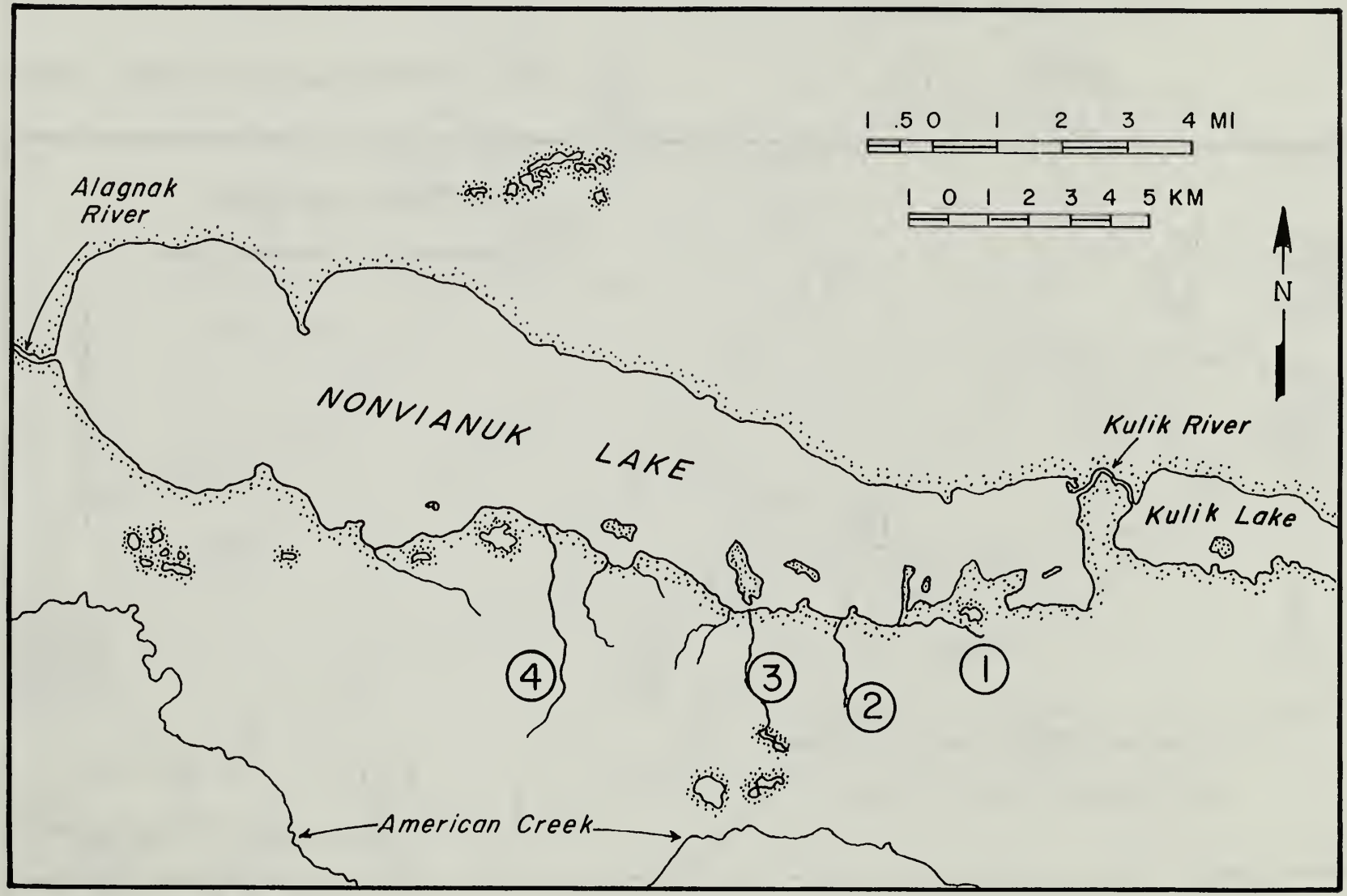

Figure 5. Nonvianuk Lake inlet streams sampled 1992.

Table 1. Lake characteristics, Katmai National Park and Preserve (from Burgner et al. 1969 and from USGS topographic maps).

System & Lakes	Altitude (m)	Area (km^2)	Maximum depth (m)	Volume (km^3)
Naknek System				
Brooks Lake	19	75	79	3.4
Coville Lake	33	33	53	0.6
Grosvenor Lake	31	73	107	3.7
Hammersly Lake	488	8	— [a]	—
Idavain Lake	223	11	21	—
Murray Lake	518	3	—	—
Naknek Lake	10	610	173	25.
Alagnak System				
Battle Lake	254	13	—	—
Kukaklek Lake	246	177	—	—
Kulik Lake	201	28	—	—
Nonvianuk Lake	192	132	—	—

[a] dash means data not available

Methods

Synoptic Lake Survey

Six of the seven large lakes that are part of the Naknek River drainage and the four large lakes at the head of the Alagnak River drainage were sampled yearly in the summers of 1990-1992 for this study (Figure 1). Idavain Lake, a tributary to the North Arm of Naknek Lake, was sampled once as our first "practice" lake in 1990 but was not retained in the yearly synoptic survey. Hammersly Lake, high in the Naknek drainage, was sampled in 1991 and 1992, but not in 1990 because of unsuitable floatplane landing conditions.

These lakes all lie within Katmai National Park and Preserve. There are small glaciers on tributaries of upper Kulik Lake and extensive glaciers on the tributary rivers of the Iliuk Arm of Naknek Lake. Additionally, the Iliuk Arm receives pumice and ash from streams that flow through the Valley of Ten Thousand Smokes, which was filled with those materials by the 1912 volcanic explosion of Novarupta (Eicher and Rounsefell, 1957).

Lakes were accessed by charter airplanes on floats, usually Cessna 206 or 207 models, during the first two weeks in August 1990-1992. We landed and anchored at the deepest spot, providing that winds were low enough to allow use of the airplane floats as a steady work platform. We selected a safer site out of the wind effects, in the cases of winds causing large waves or whitecaps at the preselected station. Six of the 11 lakes studied had no bathymetric maps (only Brooks, Coville, Grosvenor, Idavain, and Naknek lakes were mapped), but most of these lakes are typical glaciated valley lakes. In those unmapped cases, we landed near the center of both the length and width of the basin, assuming the deepest spot to be there. Naknek Lake was sampled at a site where the turbid waters of the

Iliuk Arm had mixed with the clearer waters of the North Arm. Approximate sampling stations are marked on the map of the area (Figure 1).

Secchi disk transparency was measured using a standard 20-cm weighted disk of alternating black-and-white quadrants. It was lowered on a calibrated, unstretchable, braided wire-line until it disappeared and retrieved until it could just be seen, and the depth was then read off the line at the surface. This was repeated three times and the average value calculated.

The penetration of photosynthetically active radiation (PAR) was measured at each lake each sampling period using a Li-Cor 185B quantum radiometer photometer with an LI-193SA spherical quantum sensor that measures aquatic quantum scalar (downward plus upward) irradiance. The spherical sensor was held in an underwater lowering frame which was attached to the calibrated wire-line described above. Data were taken at each meter of depth until values fell to approximately 1% of the irradiance measured immediately under the water surface. Percentage of irradiance was plotted versus depth on semi-log graph paper, and the slope of the best straight line connecting the points was calculated as the vertical attenuation coefficient of downward irradiance, K_d. This coefficient is equivalent whether the sensor used is flat (cosine) or essentially three-dimensional (scalar) (Kirk, 1994).

Samples for water color and turbidity, major ions, and nutrients were taken in triplicate with an opaque 2-L Van Dorn sampler at a depth of 2 m and delivered into 1-L cubitainers and placed in an insulated cooler. Trace metal samples were taken in the same way and delivered into new, acid pre-cleaned 250-mL Nalgene bottles and stored in a cooler. Phytoplankton samples for biomass estimates (as chlorophyll *a*) were taken with the same sampler and handled the same way as the color and turbidity samples.

Triplicate phytoplankton samples were taken at depths of 1 m, the Secchi depth, and twice the Secchi depth.

Depth profiles were taken using a Hydrolab Model 4041 multimeter fitted with temperature, pH, conductivity, and dissolved oxygen probes. Calibration of the unit was conducted every few days and whenever any sensor maintenance was required. Readings of dissolved oxygen were corrected for the altitude of the lake if it was different than the altitude at which the sensor was calibrated. Conductivity was automatically corrected to 25°C by the electronics of the meter.

Vertical hauls with a zooplankton net (0.235 m x 1 m) of 20 mesh (0.001 cm) were made in triplicate from the bottom of each lake at the sampling station. These samples were emptied into 60-mL Nalgene bottles, and these were placed into a cooler.

Upon return to the local, temporary laboratory, apparent (unfiltered) color was read at 455 nm on a HACH DR/EL 5 spectrophotometer, and turbidity was read on a HACH Model 16800 Portalab turbidimeter (nephelometer). Triplicate composite samples for chlorophyll analysis were prepared by filtering equal proportions of the samples from the three depths through a single Gelman A/E (1 μm) glass fiber filter in 1990, and two to three 1-L samples were filtered separately for each depth in 1991 and 1992. Filters were made alkaline by adding 1 mL of saturated $MgCO_3$ to the last few mL of sample filtered and were stored frozen over desiccant until processed for chlorophyll at the laboratories of the University of Alaska Fairbanks.

Alkalinity was titrated using the HACH procedure for the digital titrator (hand-held buret) on 200-mL samples using the more dilute 0.1600 N sulfuric acid cartridges. The endpoint for total alkalinity (usually a pH of 5.1) was sensed with bromcresol green-methyl red indicator. Since the initial

pH was always below 8.3, we stopped adding phenolphthalein at the beginning of the titration, because we found that it added measurable alkalinity to these low-alkalinity waters.

Chloride was titrated on 50-mL samples using HACH's digital titrator Mohr argentometric method, which uses silver nitrate, in 1990 and 1991 and on 100-mL samples using their digital-titrator mercuric nitrate method in 1992. For both of these chloride analyses, lower concentration titrant cartridges (0.22546N $AgNO_3$ and 0.2256N $Hg(NO_3)_2$) were used because of low levels of chloride in the samples. Sulfate was analyzed using HACH's turbidimetric method using (25-mL) Accuvac Ampules, which were read on the HACH DR/EL-5 spectrophotometer.

In 1990, low-range total reactive phosphate (essentially orthophosphate) and nitrite-nitrogen were measured using HACH's (25-mL) Accuvac Ampules read on the HACH DR/EL-5 spectrophotometer or by the equivalent method using powder pillows. Low-range nitrate- and nitrite-nitrogen was measured in 1990 using HACH's cadmium reduction method on 30-mL samples read on the HACH DR/EL-5 spectrophotometer. Total phosphorus samples were taken into 50-mL acid-washed Nalgene bottles, frozen, and returned to the UAF laboratories for analysis.

In 1991 and 1992, the above attempts to measure inorganic nutrients were abandoned, because essentially all of the 1990 measurements were below detection limits. Instead, triplicate samples were placed into 10-mL acid-washed screw-cap culture tubes at the field laboratory, pre-filtered if for the dissolved forms of the nutrients, and the nitrogen tubes were preserved with 1 drop of 50% sulfuric acid. These samples were shipped to the limnology laboratory of Dr. John R. Jones at the University of Missouri, Columbia, where they were analyzed for total dissolved phosphorus, total

phosphorus, total dissolved nitrogen, and total nitrogen as labeled on each tube.

Zooplankton samples were preserved at the field laboratory with 3 mL of buffered formalin and shipped to our laboratories at UAF. Trace metal samples were refrigerated at the field laboratory and shipped to UAF, where they were preserved with 0.3 mL of ultra-pure (distilled) concentrated nitric acid and shipped to Environmental Trace Substances Research Center in Columbia, Missouri, where they were acid digested for total recoverable metals and analyzed by inductively coupled plasma (ICP) scanning for 30 elements. In addition to the QA/QC conducted by the contract laboratory, we included blanks and knowns with the 1990 samples. Our triplicate samples each year were in bottles numbered out of sequence, which provided another check on the laboratory's performance. Triplicate results were extremely precise, and results on our external knowns and their own internal recovery of spikes showed acceptable accuracy.

In 1990, total phosphorus was analyzed at the UAF laboratory using persulfate digestion and a molybdenum blue colorimetric technique (Eisenreich, Bannerman, and Armstrong, 1975). The reading of the blue color was conducted on a Spectronic 700 spectrophotometer, using long path-length (4 cm), low-volume cuvettes.

In 1991 and 1992, total and total dissolved nutrients were analyzed at the University of Missouri limnology laboratory. Acidic persulfate digestion was carried out in all the tubes, and the molybdate blue species of phosphorus was read on phosphorus samples using a Milton Roy 1201 spectrophotometer. Nitrogen was read for nitrogen samples on the nitrate formed during digestion by the second-derivative spectroscopy method of Crumpton, Isenhart, and Mitchell (1992).

Chlorophyll filters were ground in a tissue-grinding tube with a Teflon® pestle driven by an electric stirring motor. Extraction was allowed in a refrigerator for 24 hours, and samples were analyzed for total chlorophyll-*a* (not corrected for phaeopigments) on a fluorometer (APHA et al., 1989). Samples for 1991 were not successfully read because of a laboratory error. Zooplankton samples were washed to remove the buffered formalin preservative and then analyzed for dry weight and ash-free dry weight (organic content) using pre-ignited and tared glass-fiber filters according to Standard Methods (APHA et al., 1989).

Data were normalized by log transformations if necessary, and data exploration and statistics were conducted with JMP™ software (SAS Institute, 1994).

Nutrient Stimulation Experiments

Lake planktonic algal stimulation bioassay experiments were conducted on Coville and Grosvenor lakes in 1992, and on Battle, Brooks, Kulik, and Nonvianuk lakes in 1993. Near-surface water was sampled and placed into 10-L cubitainers. Triplicate containers were treated with nitrogen, adding 75 µg/L using ammonium nitrate, with phosphorus adding 5 µg/L using sodium orthophosphate, with both nitrogen and phosphorus together at the above concentrations, and with no chemical additions as controls. In Coville Lake, 10 µg/L P was added in each phosphorus addition.

The cubitainers were attached to an anchored, buoyed line at one-half of the Secchi depth and allowed to incubate at ambient conditions for 4 or 5 days. When retrieved, the cubitainers were returned to the field laboratory in dark containers, and replicate subsamples were immediately filtered through GF-C glass fiber filters and treated as all other chlorophyll-*a* samples.

Streams

In 1990, Katmai National Park staff sampled some of the major lake inlets and outlets along the Alagnak and Naknek drainages (Figures 1–3). Of those streams, only certain inlets of Brooks Lake (Figure 3) were sampled repeatedly in 1991 and 1992. In 1992 some additional inlet sampling was conducted on Kulik and Nonvianuk lakes (Figures 4 and 5).

Streams were most often reached by floatplane, as described in the methods for the synoptic lake survey above, except that the plane was pulled up to shore and the work party then accessed the stream on foot. Streams were also visited by boat when they were available near the housing for the work party.

Stream discharge and associated measurements of width and average velocity of the cross-section were measured by the velocity area technique (Gregory and Walling, 1973) using a Marsh-McBirney electric-field water velocity meter and a top-setting rod. When discharge was not measured directly (1992 on Kulik Lake inlets), it was estimated visually by two limnologists using their experience.

When methods were not different between lakes and streams, they will not be repeated in this section. Suspended solids were measured on samples filtered at the laboratory (1990) or in the field (1991) according to standard methods (APHA et al., 1989). Suspended solids were not run in 1992 on Brooks Lake inlets due to accidental mishandling of the pre-ignited, pre-weighed filters by the field technicians. Conductivity, pH, and temperature were measured with a Ciba-Corning Checkmate hand-held meter with interchangeable probes. Probes were calibrated daily with standards.

Sestonic algal concentration (as chlorophyll *a*) was measured by taking a grab sample of 1 L into a Nalgene graduate cylinder, filtering it, and

handling it as above in the methods for lakes. In 1992, reactive phosphate (orthophosphate) was measured in Brooks Lake inlets using the HACH Accuvac® method. Nitrate (and nitrite) nitrogen was measured in 1992 (Brooks, Kulik, and Nonvianuk lake outlets) using the HACH low-range methods on 30-mL samples.

Quality Assurance/Quality Control

Precision of the analytical methods was assured by measurements on replicate (usually triplicate) samples. Accuracy of chemical measurements was assured by the method of standard additions in which increasing concentrations of the appropriate primary standard were added to three subsamples of a sample, and the analytical measurement made on each. Results were plotted on square-matrix graph paper, and the true value of the analyete in the sample was found graphically. This test was conducted on 5% of the samples and whenever a new batch of chemicals was opened for use. Reagent blanks were measured on reagent grade water and subtracted when necessary.

ICP samples were sent to the Trace Substances Research Laboratory (TSRL) as triplicates from each waterbody in totally randomized numbered bottles. In 1990 and 1991, check samples provided by USEPA Duluth were prepared by diluting with reagent-grade water, preserved as above with ultrapure (distilled) nitric acid, and submitted in triplicate. The TSRL also analyzed duplicate subsamples and blanks, as well as spiking samples with standards and measuring the percentage recovery of the spike. All the above tests showed TSRL results to be acceptably accurate and precise.

Results and Discussion

Lakes

Profiles.—Temperature profiles (Figures 6–16) for the Katmai lakes in late July to early August 1990–1992 illustrate the lack of persistent summer stratification which had previously been reported (Buck et al., 1978). Only one thermocline, as stated as a change greater than 1°C per meter (Wetzel, 1975), was seen on Coville Lake, July 27, 1992. However, on the same date, at a station in the center of the length of the lake, there was no thermocline. Thus, sufficiently strong winds might deepen the metalimnia that occasionally formed at depth (e.g., the "steps" in the 1992 (Figure 13) Kulik Lake temperature profile) or circulate these lakes to the bottom (e.g., the almost straight temperature profile (Figure 6) of the bottom 40 m of Battle Lake in 1992). This condition of thermal instability allows considerable heat energy to be mixed deep into those lakes. Note the 9.5°C temperature at the bottom of Battle Lake (55 m) in 1990 (Figure 6) and the 11°C temperature in the depths of Nonvianuk Lake that year (Figure 16). Of course, this sequestering of energy and the water mass mixing have implications for the growth of aquatic organisms which, everything else being equal, could be higher in these lakes than in other lakes near this latitude that summer stratify and maintain a cold (~4°C) hypolimnion. There were year-to-year variations in lake heating; note that Battle Lake (Figure 6) at 55 m is about 9.5°C in 1990 and at about 8.5°C in 1992, but only at about 5°C in 1991 when it was taken a week earlier than in 1990 and 1992. Also note that Naknek Lake was 2° cooler at 55 m in 1991 than 1990 (Figure 15), and Kulik Lake was about 1.5° cooler at 65 m in 1991 than in 1990 or 1992.

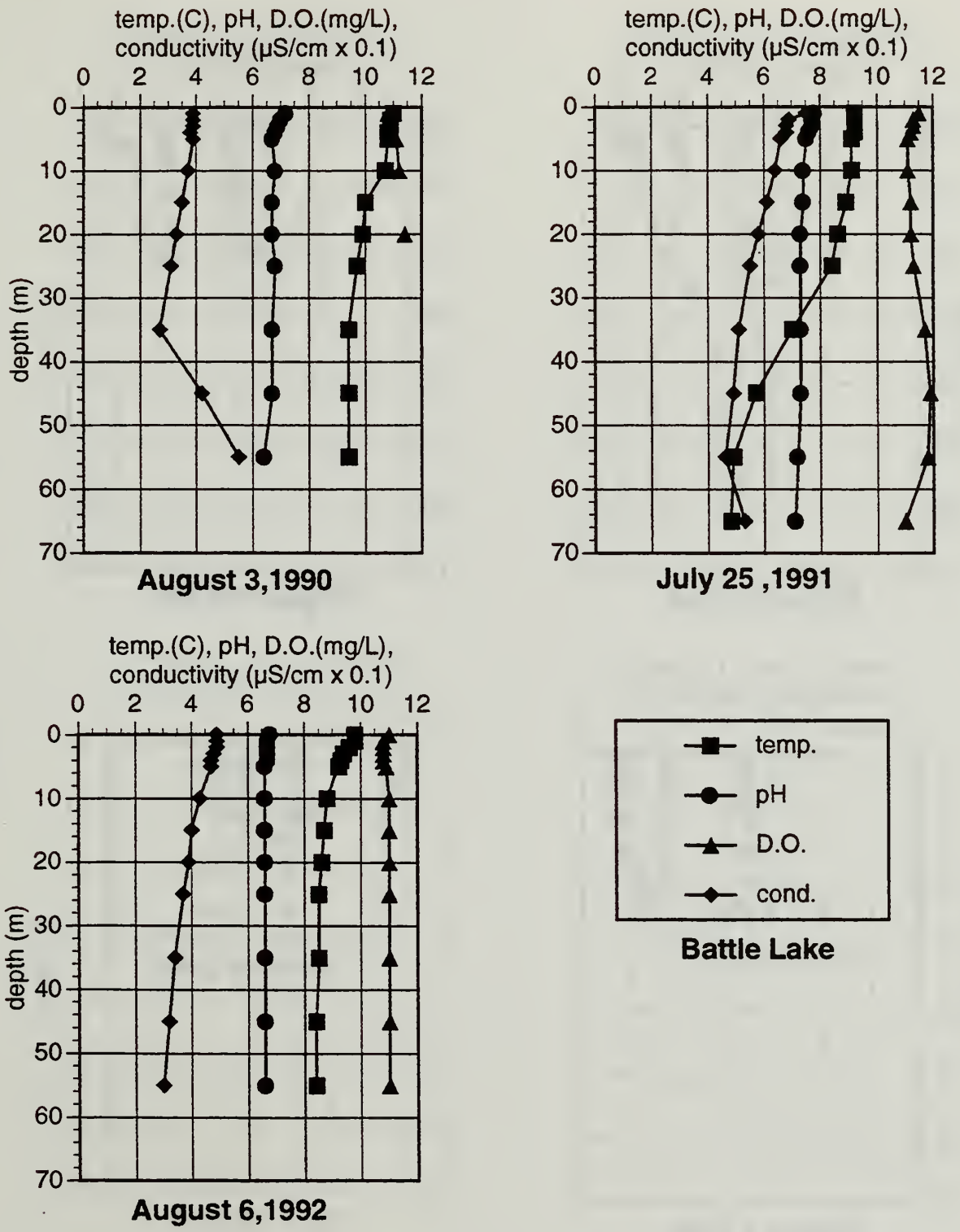

Figure 6. Depth profiles of water quality characteristics, Battle Lake.

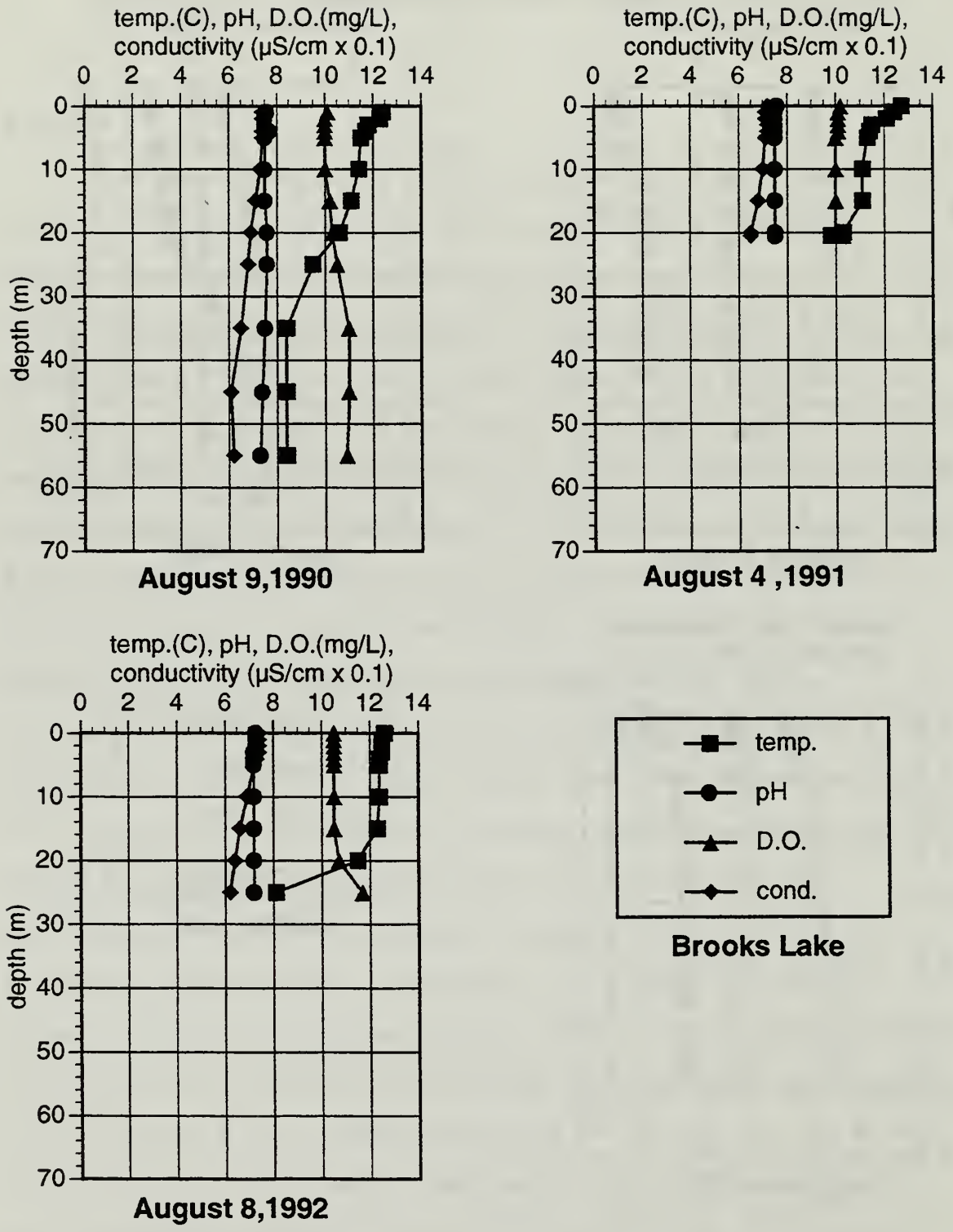

Figure 7. Depth profiles of water quality characteristics, Brooks Lake.

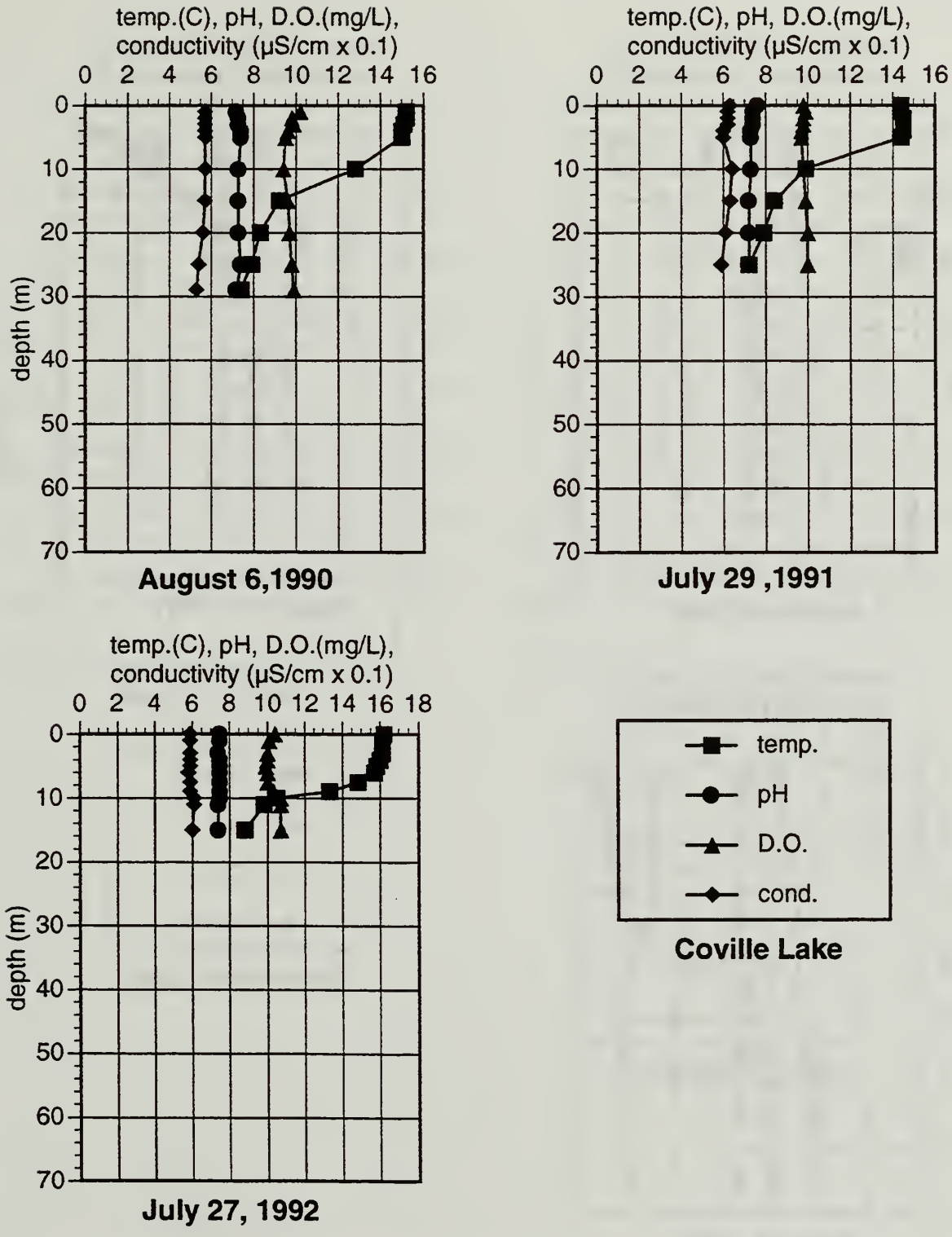
temp.(C), pH, D.O.(mg/L),
conductivity (µS/cm x 0.1)
0 2 4 6 8 10 12 14 16
depth (m)
0 10 20 30 40 50 60 70
August 6,1990
temp.(C), pH, D.O.(mg/L),
conductivity (µS/cm x 0.1)
0 2 4 6 8 10 12 14 16
0 10 20 30 40 50 60 70
July 29 ,1991
temp.(C), pH, D.O.(mg/L),
conductivity (µS/cm x 0.1)
0 2 4 6 8 10 12 14 16 18
depth (m)
0 10 20 30 40 50 60 70
July 27, 1992
temp.
pH
D.O.
cond.
Coville Lake

Figure 8. Depth profiles of water quality characteristics, Coville Lake.

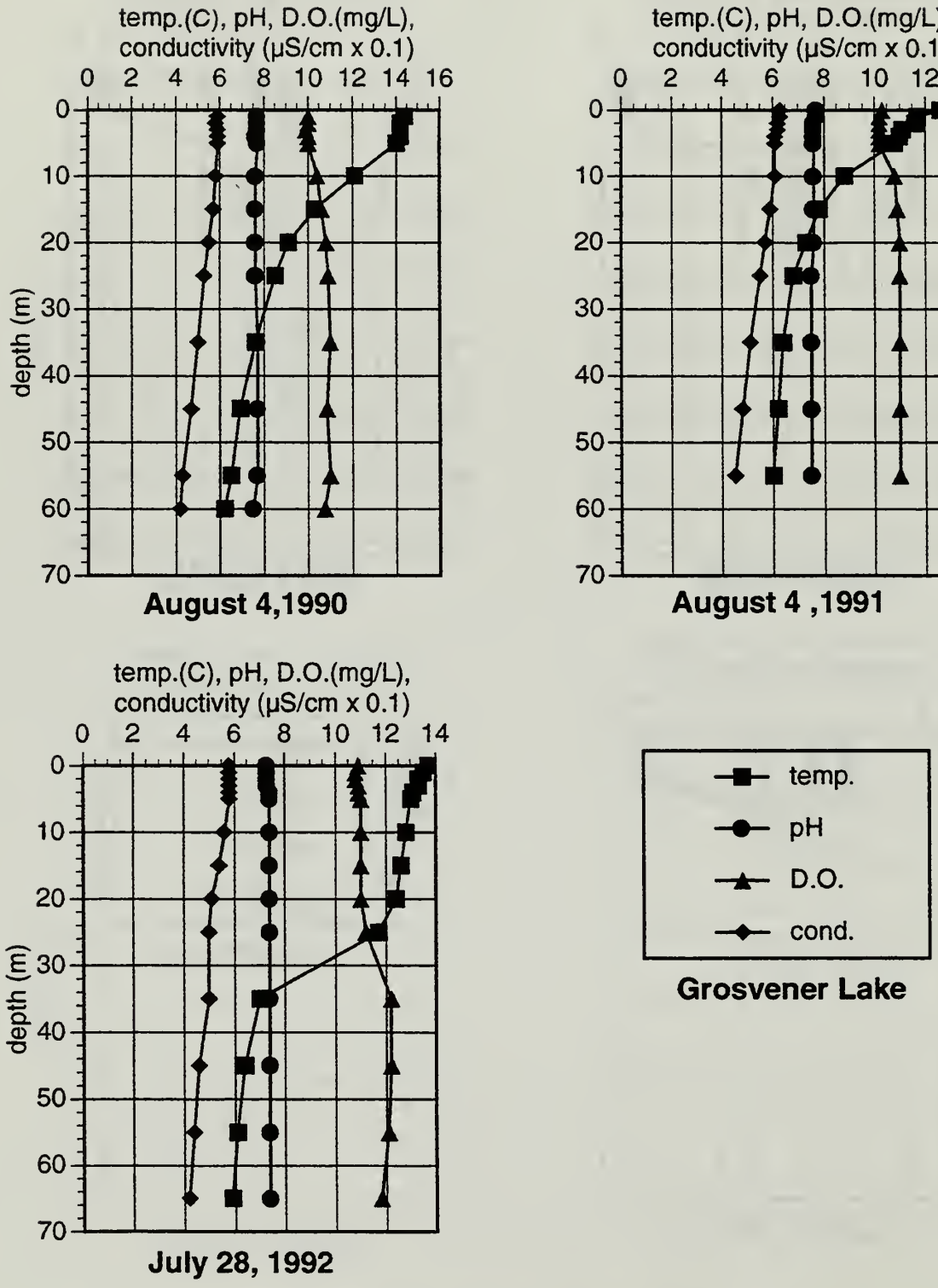

Figure 9. Depth profiles of water quality characteristics, Grosvenor Lake.

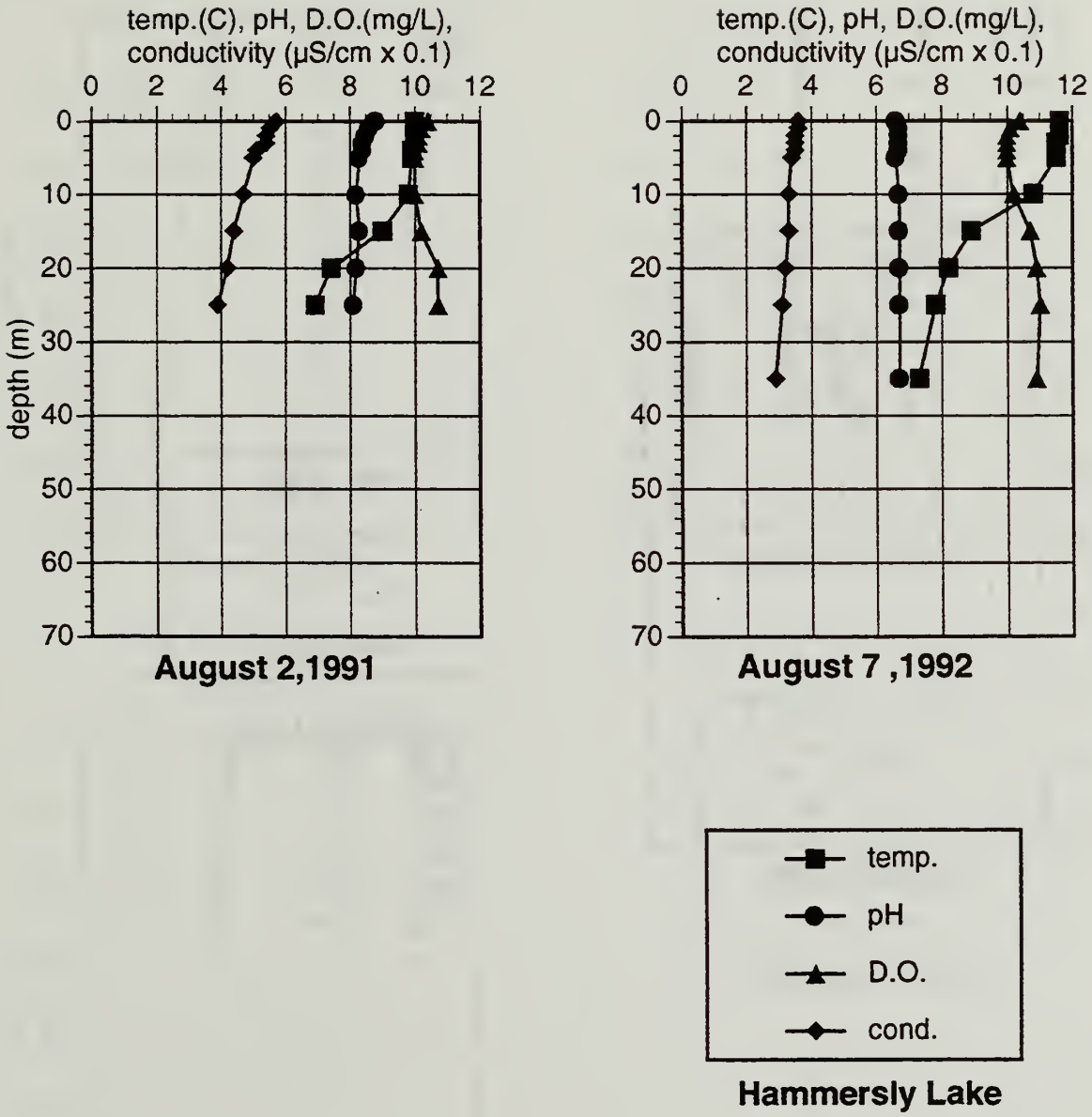

Figure 10. Depth profiles of water quality characteristics, Hammersly Lake.

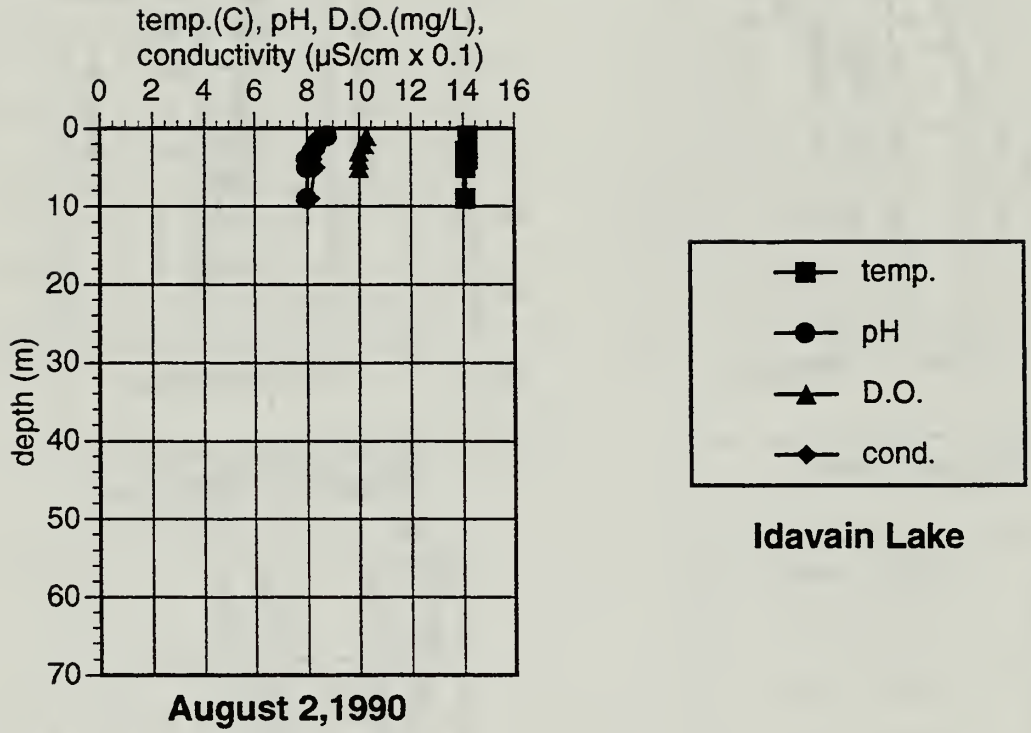

Figure 11. Depth profiles of water quality characteristics, Idavain Lake.

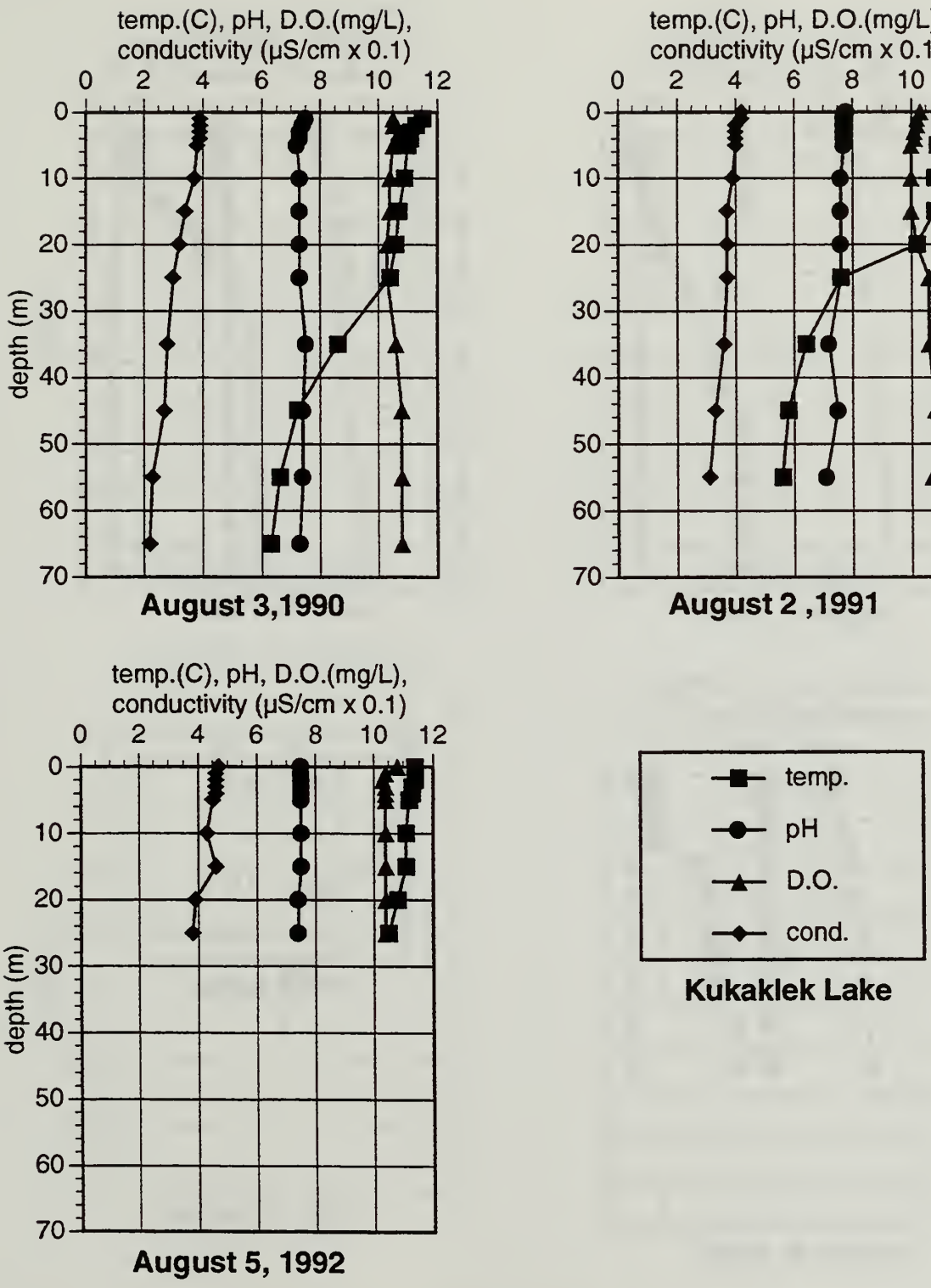

Figure 12. Depth profiles of water quality characteristics, Kukaklek Lake.

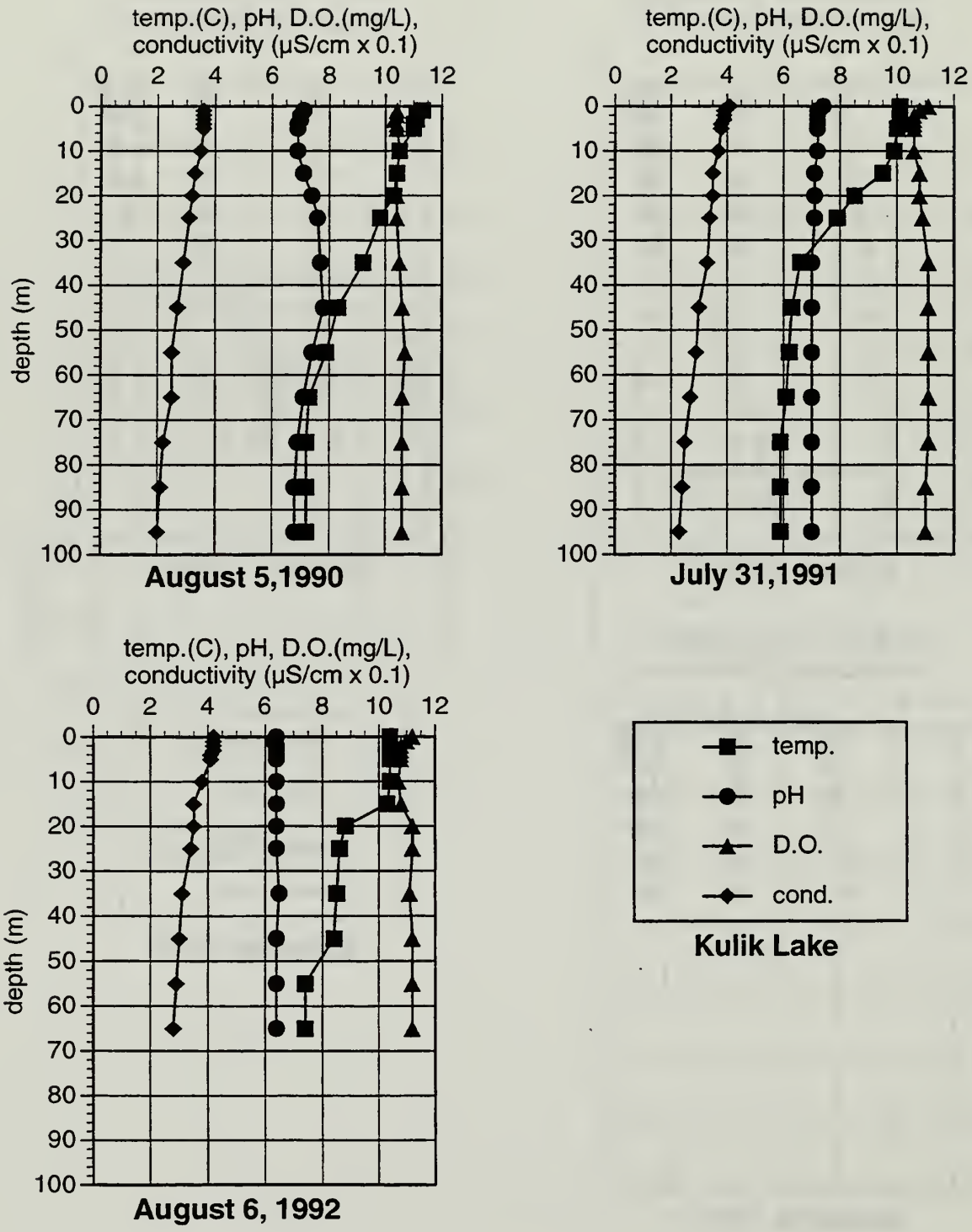
temp.(C), pH, D.O.(mg/L),
conductivity (µS/cm x 0.1)
0 2 4 6 8 10 12
depth (m)
0 10 20 30 40 50 60 70 80 90 100
August 5,1990
temp.(C), pH, D.O.(mg/L),
conductivity (µS/cm x 0.1)
0 2 4 6 8 10 12
0 10 20 30 40 50 60 70 80 90 100
July 31,1991
temp.(C), pH, D.O.(mg/L),
conductivity (µS/cm x 0.1)
0 2 4 6 8 10 12
depth (m)
0 10 20 30 40 50 60 70 80 90 100
August 6, 1992
temp.
pH
D.O.
cond.
Kulik Lake

Figure 13. Depth profiles of water quality characteristics, Kulik Lake.

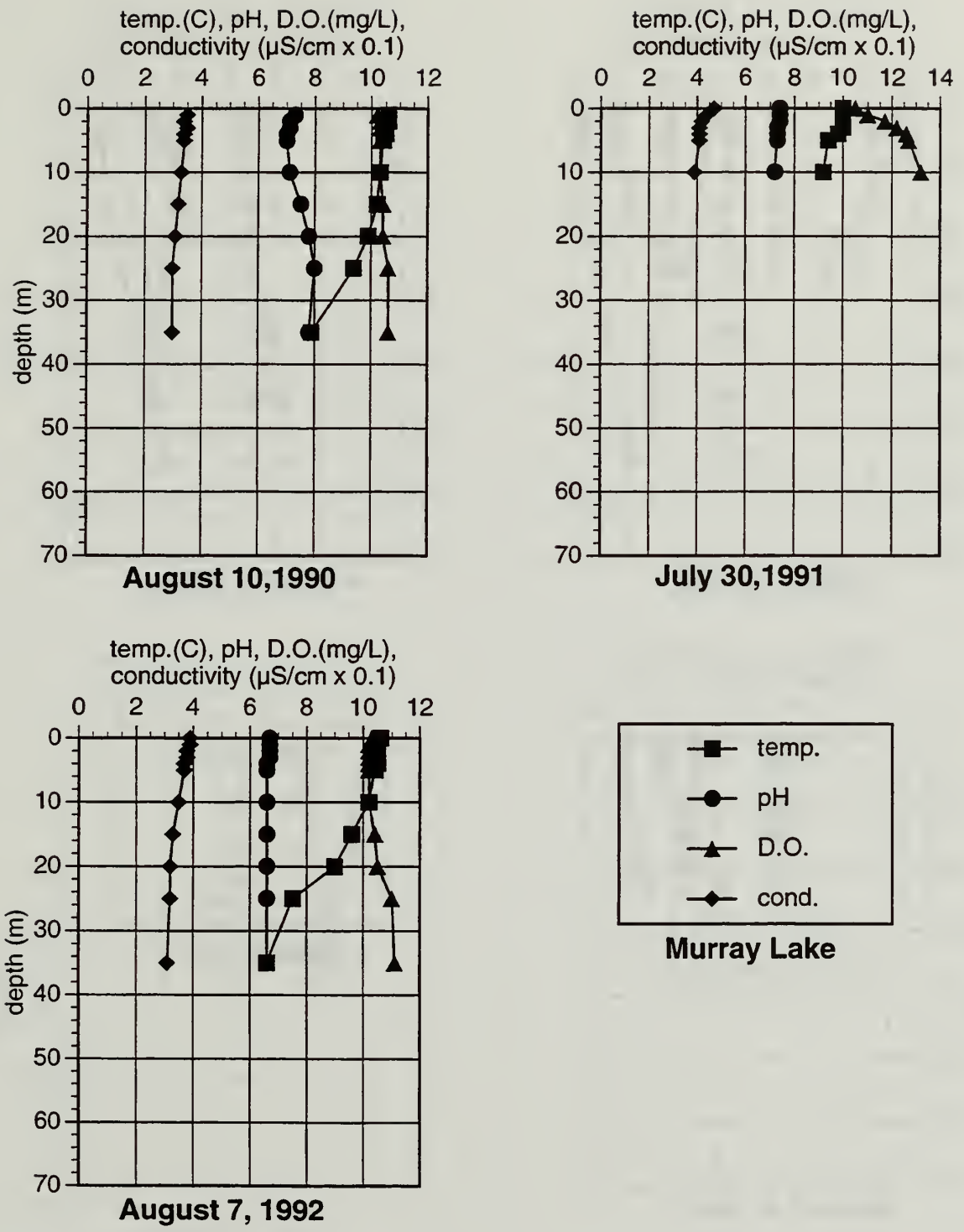

Figure 14. Depth profiles of water quality characteristics, Murray Lake.

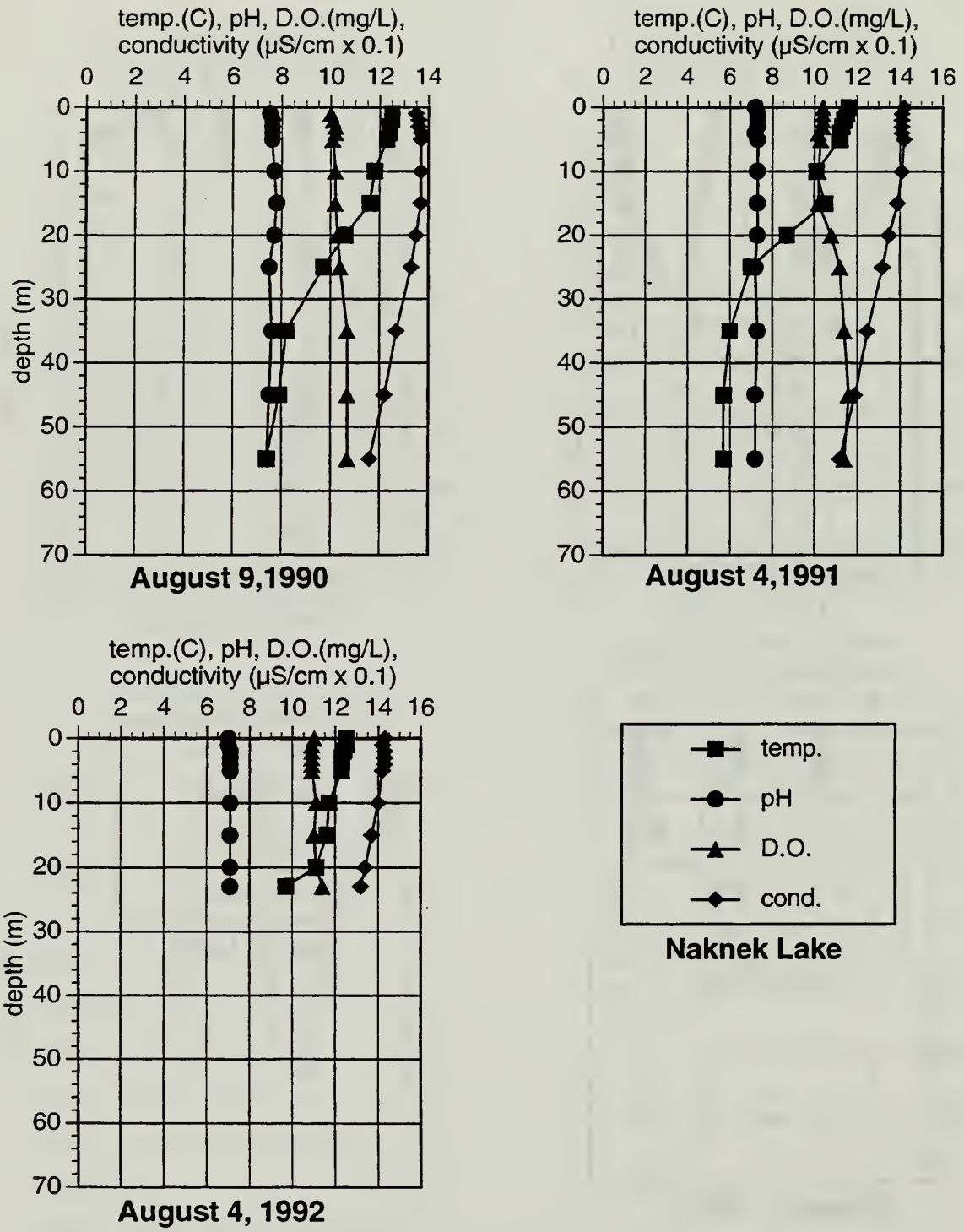

Figure 15. Depth profiles of water quality characteristics, Naknek Lake.

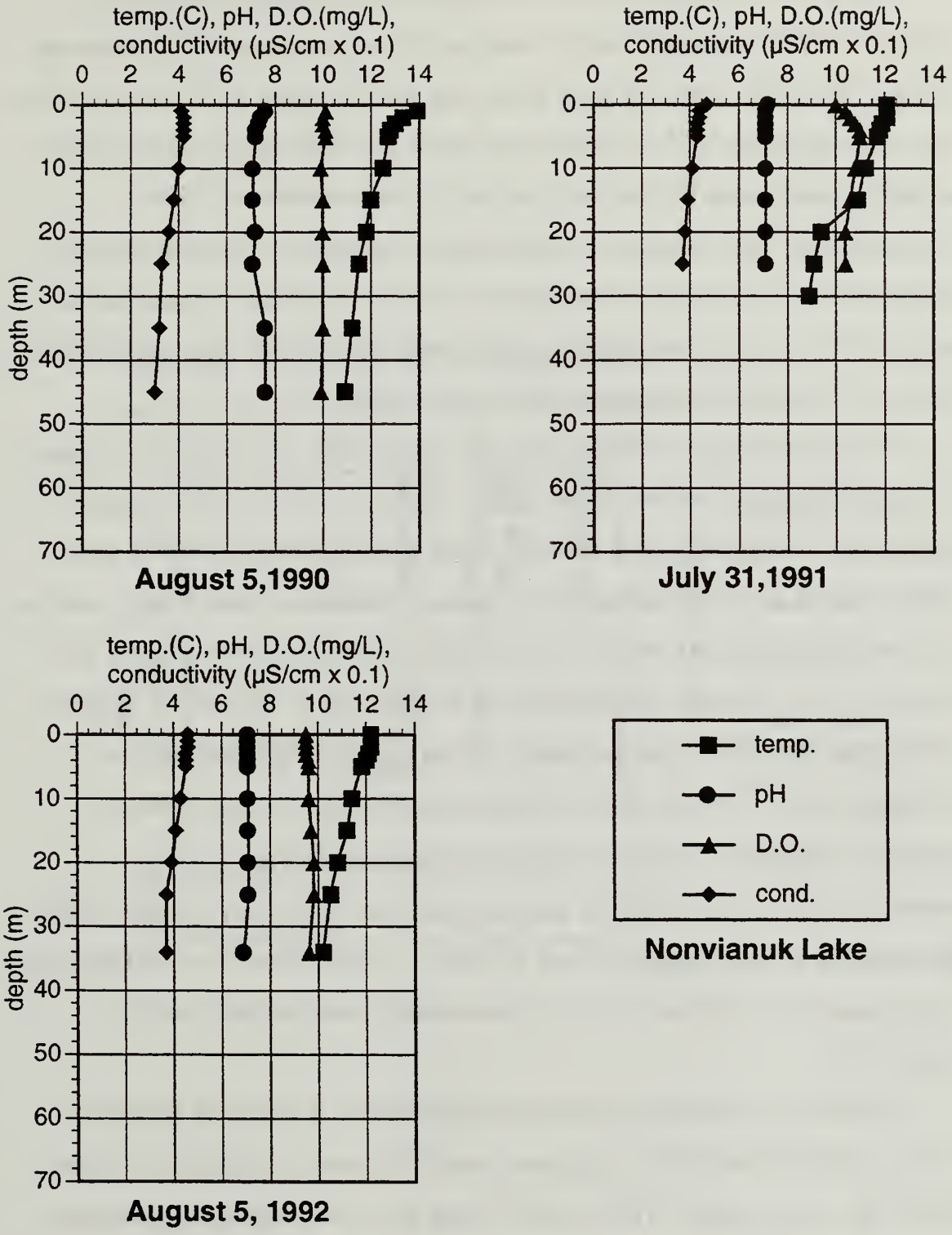

Figure 16. Depth profiles of water quality characteristics, Nonvianuk Lake.

Buck et al. (1978) concluded that maximum surface temperatures might be 12°C, except for Coville Lake, which might reach 15°C. However, during 1990–1992, some of these lakes met and exceeded 14°C, and Coville Lake even exceeded 16°C. Long, calm, sunny periods during summer there probably could warm the surface temperature above what has been measured, and "hard" summer stratification is probably an occasional but rare occurrence. Therefore, these lakes would be classified as monomictic—mixing all the ice-free period. Since they warm above 4°C, they would more correctly be called warm thereimictic (Cole, 1994).

Dissolved oxygen profiles (Figures 6–16) were all orthograde, typical of oligotrophic lakes, wherein the major influence on dissolved oxygen is temperature. While algal and vascular plant growth was so low as to have little influence on dissolved oxygen, diurnal pH differences in Battle Lake in 1991, where surface pH was 6.1 at 8:30 a.m. on July 26, 1991 (Figure 17), but about 7.3-7.7 the previous afternoon at about 3 p.m. (Figure 6), may be due to algal demand on the inorganic carbon species. This lake has low alkalinity, about 2.4 mg/L as $CaCO_3$, and therefore is poorly buffered against pH changes. These pH differences between the two profiles, however, may instead be due to sampling at closer proximity (on July 26) to the influence of Iron Springs Creek (Battle 1), which flows into the lake with a pH measured in 1990 at 4.4 and unmeasurably low titrable alkalinity (Table 18).

Conductivity usually decreased with depth in these lakes (Figures 7-16), except in Battle Lake (Figures 6 and 17) where it increased near the bottom in some profiles. This "saltier" layer near the bottom was probably from waters flowing in from some of the inlets, plunging to depth because of higher density caused by lower temperature and higher concentrations of

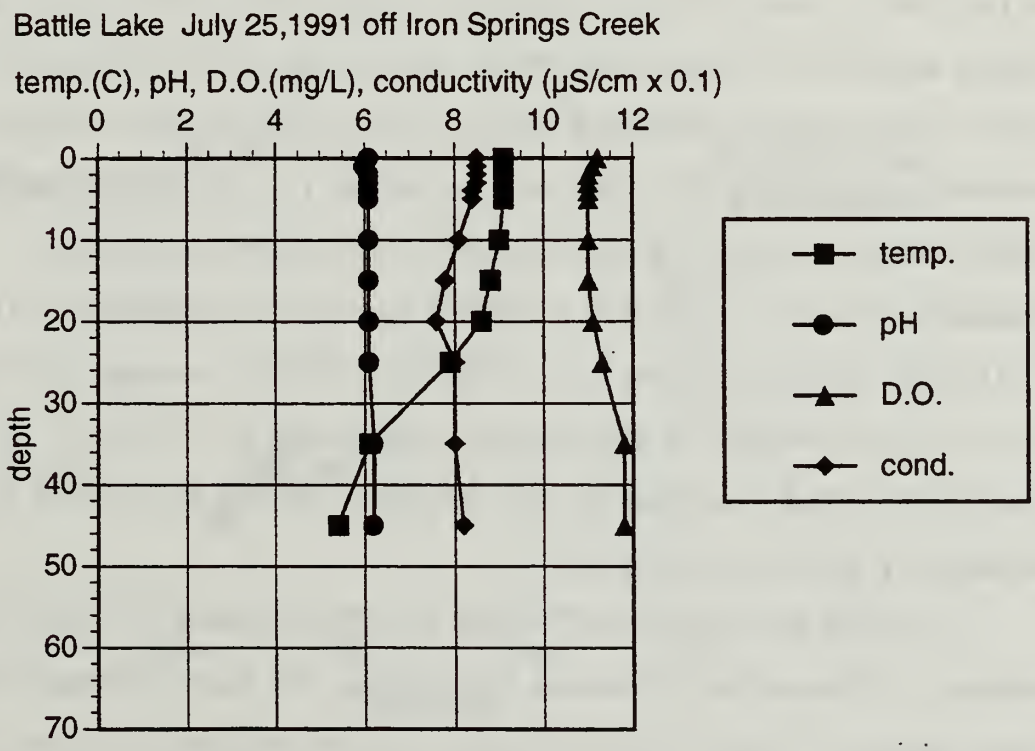

Figure 17. Depth profiles of water quality characteristics, Battle Lake offshore from Iron Springs Creek, 8:30 a.m., July 26, 1991.

major and trace metal ions. Note also that Naknek Lake where profiled had a conductivity more than twice as high as its sister lakes.

Major Ions.—Naknek Lake was the "saltiest" of the 11 major Katmai National Park and Preserve lakes with 3.20 meq/L major ions (Appendix A4) and a conductivity of about 139 µS/cm (Figure 15). The lowest major ion sum was found in Murray Lake at 0.58 meq/L (Appendix A4) and with a conductivity of 39 µS/cm (Figure 14). Murray Lake is at the highest altitude and Naknek the lowest. Among the major cations and anions, nonparametric statistical analysis shows that altitude is strongly inversely correlated with 3-year average calcium ($\rho = -0.9091$; $p = 0.0001$), 1991 potassium values (the only year with values above the method detection limit) ($\rho = -0.8528$; $p = 0.0017$), average magnesium ($\rho = -0.8091$; $p = 0.0026$), average sodium ($\rho = -0.8091$; $p = 0.0026$), average alkalinity ($\rho = -0.7909$; $p = 0.0037$), and average conductivity ($\rho = -0.7182$; $p = 0.0128$). These relationships were expected since as water flows down drainages, it tends to pick up salts.

Of all the major ions, only sulfate and chloride were not found related to altitude. When ternary diagrams were plotted, the major cations grouped tightly together (Figure 18), but the major anions separated into three groups (Figure 19). Sulfate concentration was proportionally highest in Battle Lake (and bicarbonate alkalinity and chloride lowest) and intermediate in Kulik and Naknek lakes. The rest of the lakes were higher in proportion of chloride and spread from intermediate to high in their proportion of bicarbonate alkalinity.

All 11 lakes were dominated by calcium among the major cations, with sodium next and magnesium only slightly proportionally less than sodium. Potassium was least dominant of the cations among these lakes

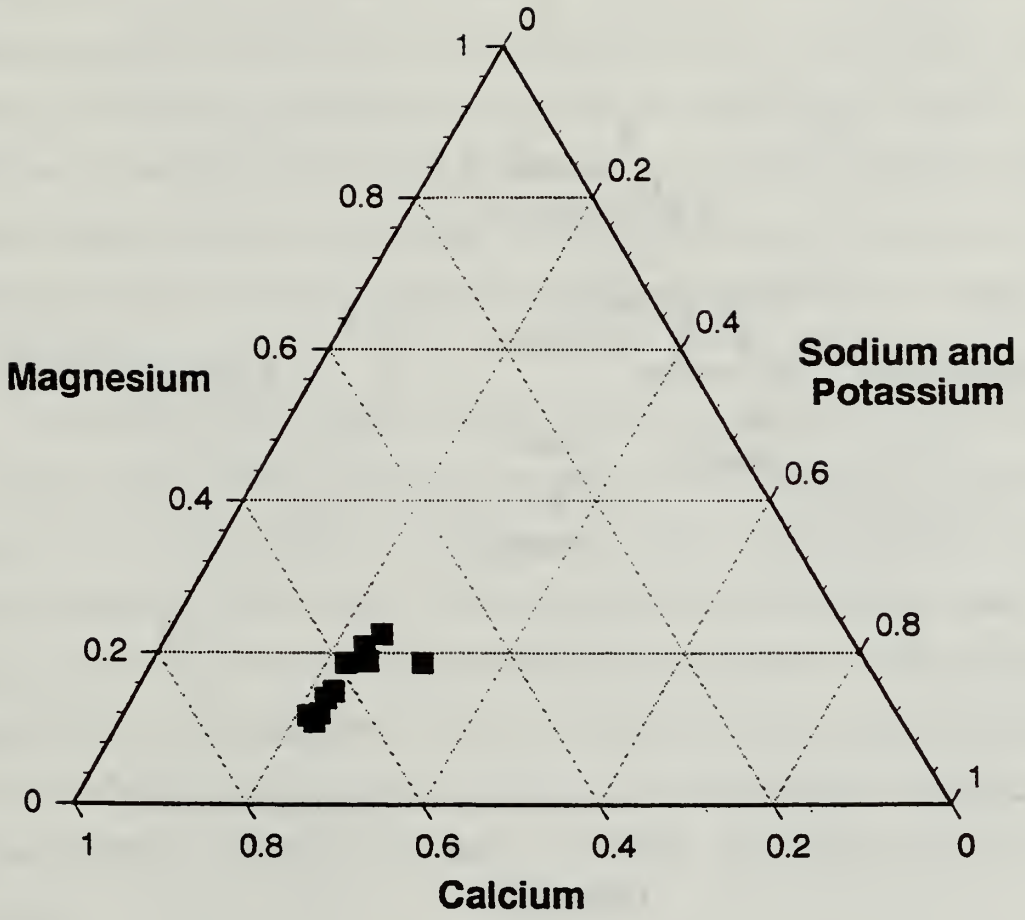

Figure 18. Ternary diagram of major cations of the lakes of Katmai National Park and Preserve.

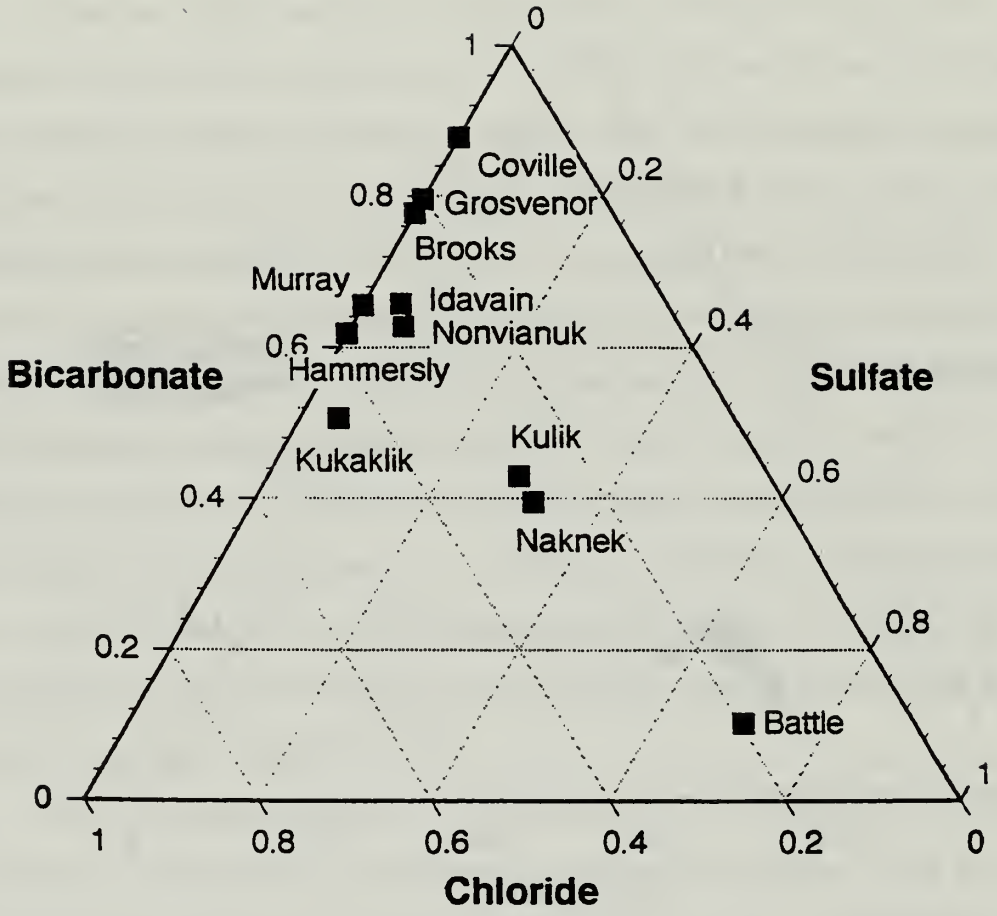

Figure 19. Ternary diagram of major anions of the lakes of Katmai National Park and Preserve.

(Figure 20). Therefore, based on cations, these lakes resemble average temperate lakes (Wetzel, 1983).

However, when anions are also considered (Figure 20), Brooks, Coville, Grosvenor, Hammersly, Idavain, Murray, and Nonvianuk lakes were typical calcium bicarbonate lakes, but Kukaklek Lake could be called a calcium chloride-bicarbonate lake, and Naknek Lake might be called a calcium sulfate-bicarbonate lake. Kulik Lake had equal proportions of the three major anions and was difficult to classify, chemically. Battle Lake was an unusual type, a calcium sulfate lake, with sulfate representing about 71% of the anions.

The higher than normal (Wetzel, 1983) representation of sodium and chloride in these lakes is probably due to their proximity to Bristol Bay and Cook Inlet of the Pacific Ocean, and the source of sodium chloride to the lakes is probably precipitation. The sulfate that was also proportionately high in these lakes, especially in Battle, Kulik, and Naknek lakes, probably came from weathering of rock sources of reduced sulfur in the watersheds, but may also be from geothermal sources. Kulik Lake had one inlet that was apparently from a warm or hot spring that will be described in the section on streams.

These lakes were not suspected to be influenced by anthropogenic acid precipitation, but the low ratio of alkalinity to calcium plus magnesium ions, especially in the Alagnak drainage, while probably natural, is quite unusual. Schindler (1988) points out that this ratio is usually 0.8 to 1.1 in acid-vulnerable areas not experiencing acid rain. Further, he points out that broad lake surveys have not found lakes outside the above range except where minerals high in sulfur are weathering (probably true of the Alagnak drainage), and then this ratio seldom is less than 0.6 in pristine areas. The highest altitude lakes in the Naknek drainage—Hammersly and Murray—

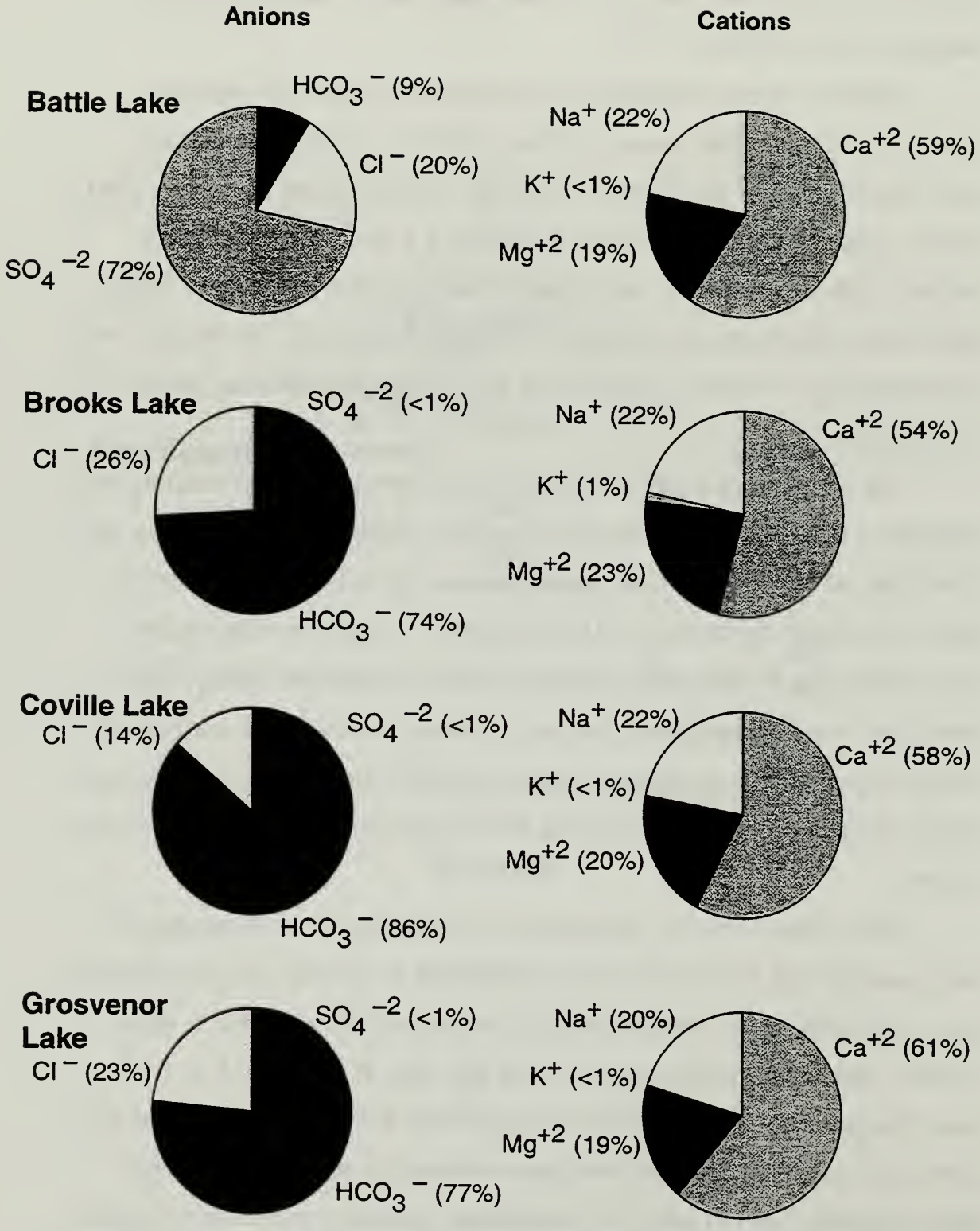

Figure 20. Diagrams of the anion and cation proportions of the lakes of Katmai National Park and Preserve.

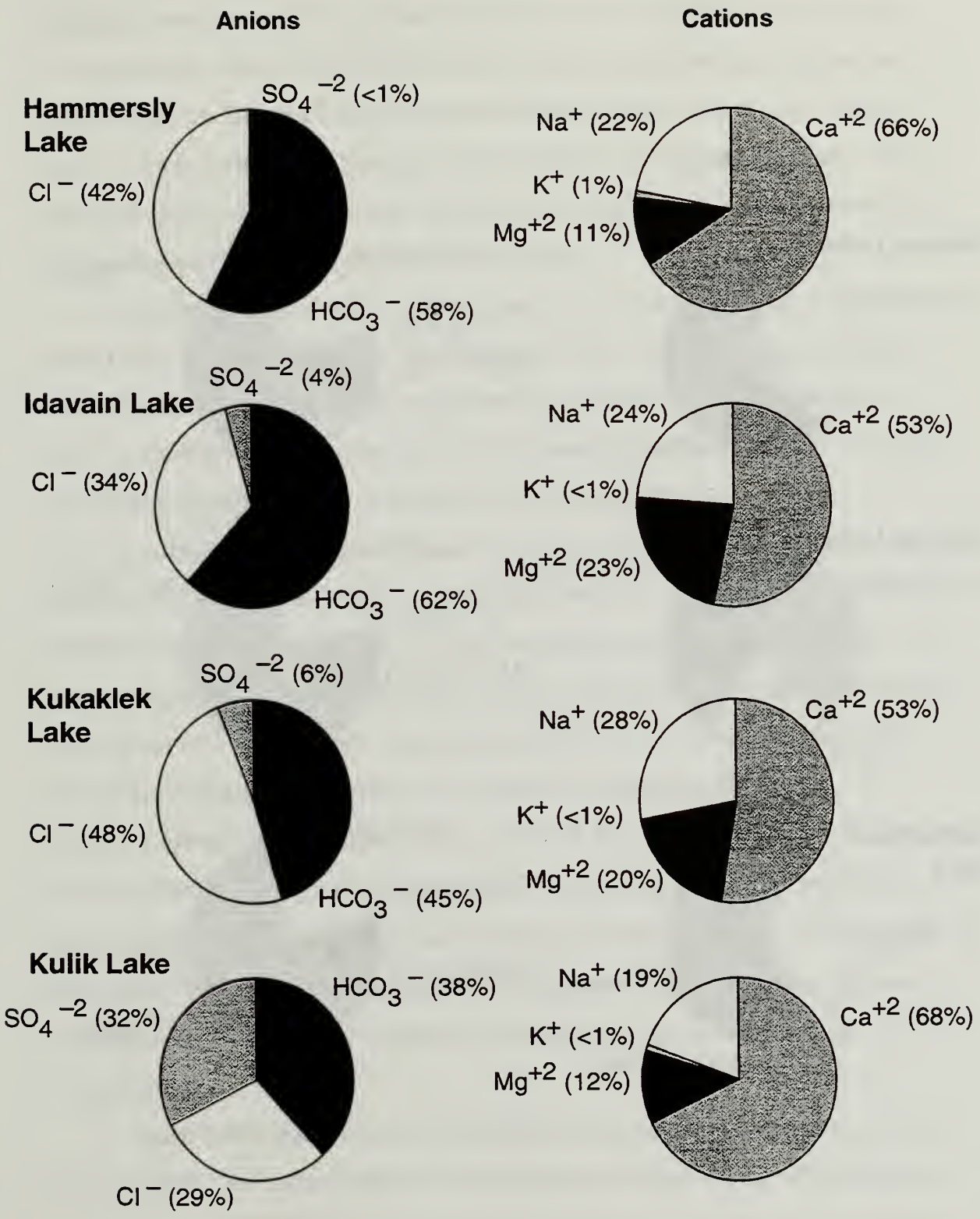

Figure 20. Continued.

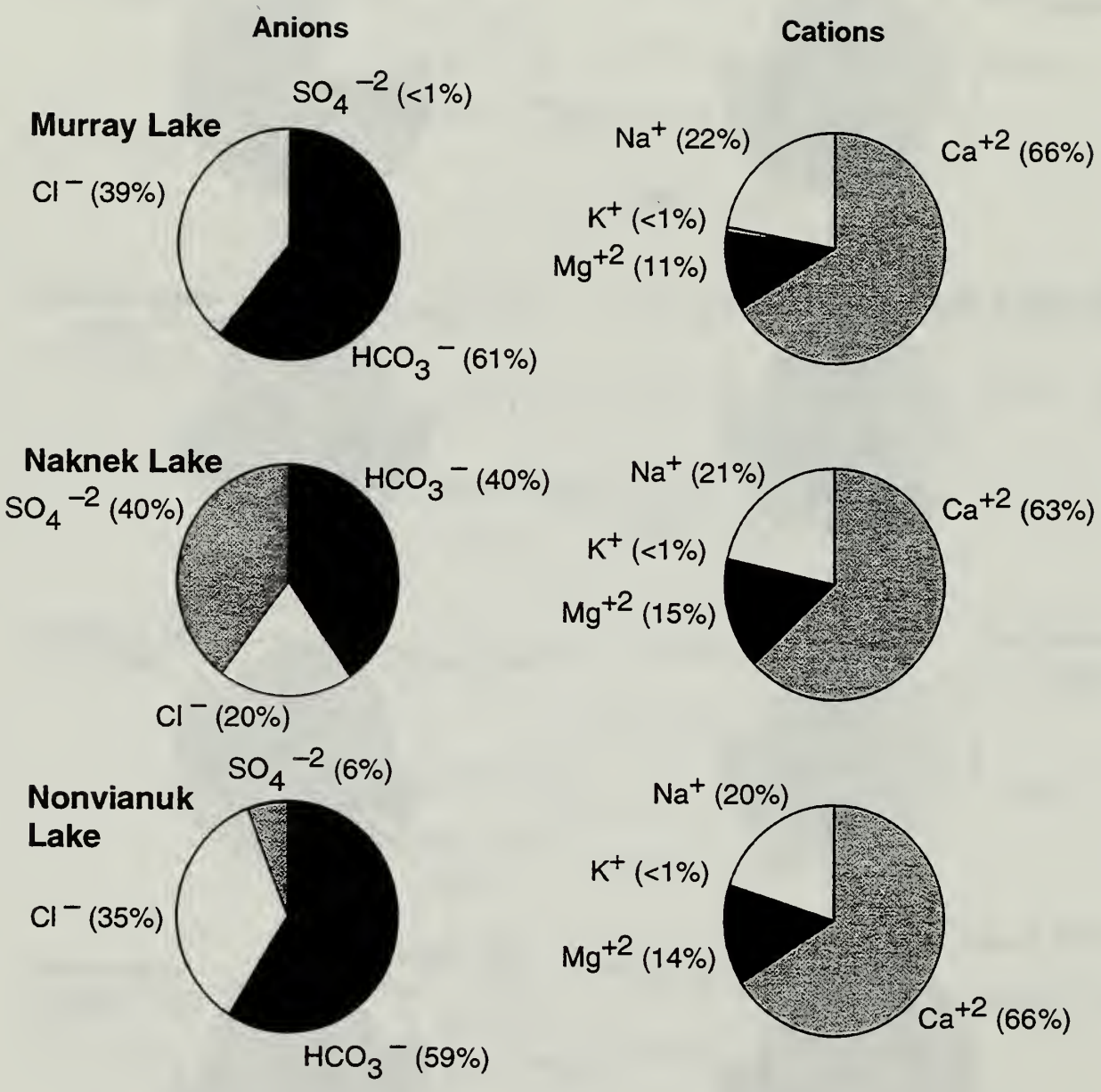

Figure 20. Continued.

had this ratio equal to 0.8, at the bottom of the normal range. In the Alagnak drainage, however, all four of the lakes were lower. Nonvianuk Lake was 0.7, Kukaklek Lake was 0.6, Kulik Lake was 0.5, and Battle Lake was an astounding 0.2. Much of the watershed of Battle Lake is bare rock, and a major inlet is fed by Iron Springs Lake, which, according to Gunther (1992), has a low pH (3.65) and a high sulfate content (1.5 meq/L), and is also high in aluminum (7.4 meq/L) and zinc (4.8 meq/L).

Gunther (1992) declares these lakes to be acid-vulnerable, especially those of the Alagnak drainage (compared to those of the Naknek drainage), and attributes the cause to the low alkalinity and high sulfate content of those lakes. However, had he sampled Naknek Lake, he would have found it to have the highest sulfate content of all the large lakes he sampled. Additionally, at least in the abstract of the paper, he attributes the low alkalinity of the Alagnak lakes to their high sulfate content. In fact, the high sulfate content has no influence on the alkalinity and makes these lakes less acid-vulnerable than they would be without it. Much of the acid-neutralizing capacity in this type of lake is generated in-lake by microbial reduction of sulfate and nitrate (Schindler et al., 1980). During this reduction the microbes are oxidizing organic materials with the oxygen from the sulfate ion, and producing H_2S or elemental sulfur, which are not acid producers. The independence of alkalinity and sulfate was clearly shown in the data of this project for Naknek Lake, where the highest sulfate concentration was accompanied by the highest alkalinity concentration (in Naknek Lake) (Appendix A).

These lakes then would be vulnerable to acid deposition, particularly those that are low in both sulfate and alkalinity: Kukaklek and Battle lakes.

Trace Elements.—Of the trace elements tested by ICP (Appendix B), most were not found above the laboratory's stated detection limits—they and their detection limits were Ag (detection limit of 0.01 mg/L), As (0.04 mg/L), Be (0.0006 mg/L), Bi (0.04 mg/L), Cd (0.003 mg/L), Co (0.01 mg/L), Cr (0.01 mg/L), Cu (0.003 mg/L), Li (0.002 mg/L), Mo (0.005 mg/L), Ni (0.01 mg/L), Pb (0.04 mg/L), Sb (0.04 mg/L), Se (0.08 mg/L), Sn (0.05 mg/L), Ti (0.003 mg/L), Tl (0.08 mg/L), V (0.004 mg/L), and Zn (0.003 mg/L). To assure compliance with finished (as treated for public use) drinking water standards that were in place in 1992, the method used (ICP) did not have low enough detection limits for lead or selenium. The ICP methods also would not assure compliance with the water quality criteria (in place in 1991) for the protection of freshwater aquatic life from chronic harmful effects for silver (Ag), cadmium (Cd), lead (Pb), or selenium (Se). Also, antimony (Sb) had a proposed freshwater aquatic life chronic criterion of 30 µg/L, and the ICP method did not have a low enough detection limit for determining exceedances.

When trace element measurements were near the method detection limit, the confidence intervals around the mean values for three replicates were often as high or higher than the mean value. When two of the replicates measured above the detection limit, but the third was reported at the detection limit, it was set at zero and averaged with the other two. Only those instances where the element was detected all 3 years, and the mean value was well above the detection limit, will be discussed.

The ICP analyses were for 31 mostly metallic elements and included those of the major freshwater cations: calcium, magnesium, potassium, and sodium, which have been discussed above under major ions. Other cationic plant macronutrients—iron, manganese, and silicon—were measured in all the lakes, and iron and silicon varied together ($\rho = 0.7352$; $p = 0.0099$) and

with calcium ($\rho = 0.7306$; $p = 0.0107$ and $\rho = 0.7818$; $p < 0.0045$, respectively). While silicon varied significantly with conductivity ($\rho = 0.7727$; $p = 0.0053$), iron did not. Manganese did not vary significantly with any other measurable ion, nor with conductivity or altitude.

Of the remaining elements found measurable, strontium was ubiquitous and varied with conductivity among the lakes ($\rho = 0.8757$; $p < 0.0004$) and with conductivity's ion correlates. The geologic source of strontium was evident from its strong inverse relationship with altitude ($\rho = -0.9079$; $p = 0.0001$). Barium was also measurable but independent of other ions. Aluminum was about double to triple the detection limit in Battle Lake during the synoptic survey all 3 years measured, and in 1991, when a trace metal profile was conducted at various depths (Table 2), it was seen to be undoubtedly elevated, at least between 5 m and 20 m. This condition was attributed to the low alkalinity and high sulfate concentrations of Battle Lake. Boron was only found in Naknek Lake, most probably contributed by volcanic springs (CRC Handbook of Chemistry and Physics, 1982-1983). None of the measurable elements exceeded water quality criteria in any of these lakes, except perhaps for aluminum in Battle Lake where the freshwater chronic criterion for the protection of aquatic life appeared to be exceeded. While there are many examples of natural exceedances of water quality criteria without apparent harm to the local organisms, further additions of the particular pollutant should not be allowed in waste discharges.

Nutrients and Planktonic Chlorophyll.—Analyses of samples from the first (1990) synoptic survey showed the difficulty of measuring nutrients in the Katmai lakes (Table 3). Total phosphorus was at or below the detection limit of the method for more than half of the lakes, despite the

Table 2. Mean (± 95% CI, n=3) trace elements (concentrations) (mg/L) measured at various depths in Battle Lake, Katmai National Preserve, July 26, 1991.

	Al	Ba	Mn	Sr
1 m	0.05 ± 0.03	0.0034 ± 0.0001	0.023 ± 0.001	0.014 ± 0.001
2 m	0.04 ± 0.04	0.0035 ± 0.0003	0.023 ± 0.003	0.015 ± 0.000
3 m	0.04 ± 0.04	0.0040 ± 0.0002	0.024 ± 0.000	0.015 ± 0.000
4 m	0.04 ± 0.01	0.0035 ± 0.0004	0.025 ± 0.001	0.015 ± 0.000
5 m	0.06 ± 0.09	0.0040 ± 0.0004	0.023 ± 0.005	0.015 ± 0.000
10 m	0.06 ± 0.04	0.0036 ± 0.0003	0.024 ± 0.000	0.015 ± 0.000
20 m	0.06 ± 0.01	0.0035 ± 0.0005	0.023 ± 0.005	0.015 ± 0.003
30 m	0.04 ± 0.03	0.0035 ± 0.0001	0.024 ± 0.003	0.015 ± 0.001
40 m	0.03 ± 0.01	0.0035 ± 0.0003	0.026 ± 0.004	0.015 ± 0.001
50 m	< 0.03	0.0033 ± 0.0013	0.026 ± 0.012	0.014 ± 0.005

Table 3. Mean (±1 SD) total phosphorus and planktonic chlorophyll concentrations (µg/L) of lakes of Katmai National Park and Preserve, 1990 (n=3).

	TP	Total Chlorophyll-a
Battle	≤ 3.0	0.16 ± 0.01
Brooks	5.7 ± 1.4	0.37 ± 0.04
Coville	13.0 ± 8.0	0.56 ± 0.01
Grosvenor	≤ 3.0	0.45 ± 0.03
Hammersly	—	—
Idavain	22.0 ± 5.0	1.02 ± 0.05
Kukaklek	≤ 3.0	0.28 ± 0.03
Kulik	≤ 3.0	0.35 ± 0.04
Murray	17.0 ± 16.0	0.23 ± 0.03
Naknek	≤ 3.0	0.51 ± 0.03
Nonvianuk	≤ 3.0	0.31 ± 0.01

use of an extended path length cell (4 cm) in the spectrophotometer. Total nitrogen was so low that it could not be successfully measured by the method chosen, which was Auto Analyzer analysis of nitrite after persulfate digestion and cadmium reduction.

Samples analyzed in 1991 and 1992 at the University of Missouri Limnology Lab were above their method detection limits (Tables 4-6). Nitrogen values were lower in 1991 (Table 4) than in 1992 (Table 6), and phosphorus values trended slightly higher but were not significantly higher. Unfortunately, all planktonic chlorophyll values for 1991 were lost due to improper application of technique. The higher concentrations of chlorophyll in 1992 than in 1990 may be due to nutrients provided by the historically high sockeye salmon run of 1991, but this is speculation. Intense sampling during and after the run would have been necessary to demonstrate this result. One hint that the higher chlorophylls of 1992 may have had another cause is that Murray Lake, without a salmon run, was also higher in chlorophyll in 1992.

A profile of nutrient conditions in Battle Lake, 1991 (Table 5), illustrates a uniform distribution of nutrients with depth and the high variability of measurements when near the method detection limits. The standard deviation averaged 26% ± 19% of the mean values for total nitrogen and 36% ± 17% for total phosphorus.

Since all chlorophyll-*a* values are under 4 µg/L, all these lakes would classify as oligotrophic (Welch, 1980). Their importance as sockeye salmon nursery lakes may have something to do with thermal and mixing conditions, as mentioned earlier in the section on profiles, as well as on their nutrient conditions and resultant trophic structure.

Thirty years previously, Goldman (1960) found Brooks and Naknek lakes and nearby Becharof Lake to be nitrogen limited. Our nutrient data,

Table 4. Mean (±1 SD; n=3) nitrogen and phosphorus concentrations (µg/L) of lakes of Katmai National Park and Preserve, 1991 (T=total; D=dissolved).

	TN	TDN	TP	TDP	TN/TP
Battle	192 ± 19	162 ± 30	3 ± 2	4 ± 3	64
Brooks	68 ± 21	51 ± 30	7 ± 2	4 ± 1	10
Coville	77 ± 18	72 ± 14	12 ± 2	8 ± 2	6
Grosvenor	153 ± 23	146 ± 39	5 ± 1	5 ± 1	31
Hammersly	170 ± 73	84 ± 18	5 ± 2	5 ± 2	34
Kukaklek	56 ± 56	49 ± 12	6 ± 1	5 ± 2	9
Kulik	347 ± 38	333 ± 39	6 ± 2	5 ± 2	58
Murray	118 ± 18	118 ± 22	6 ± 1	5 ± 0	20
Naknek	87 ± 17	97 ± 57	7 ± 2	4 ± 1	12
Nonvianuk	143 ± 20	140 ± 2	6 ± 1	5 ± 1	24

Table 5. Depth profile of mean (±1 SD; n=3) nitrogen and phosphorus concentrations (µg/L) of Battle Lake, Katmai National Park and Preserve, July 25, 1991 (T=total; D=dissolved).

	TN	TDN	TP	TDP
1 m	249 ± 99	120 ± 97	5 ± 2	5 ± 2
2 m	196 ± 12	177 ± 47	4 ± 2	4 ± 2
3 m	156 ± 34	359 ± 363	4 ± 2	8 ± 3
4 m	207 ± 89	127 ± 57	4 ± 1	8 ± 6
5 m	373 ± 170	177 ± 43	5 ± 1	3 ± 1
10 m	233 ± 117	199 ± 52	4 ± 2	4 ± 1
20 m	338 ± 233	232 ± 24	4 ± 2	5 ± 1
30 m	190 ± 10	221 ± 108	2 ± 1	7 ± 2
40 m	208 ± 10	166 ± 19	3 ± 1	12 ± 5
50 m	216 ± 40	188 ± 11	3 ± 0	7 ± 5

Table 6. Mean (±1 SD; n=6) nitrogen, phosphorus, and chlorophyll concentrations (µg/L) of lakes of Katmai National Park and Preserve, 1992 (T=total; D=dissolved).

	TN	TDN	TP	TDP	Total Chl. a
Battle	220 ± 10	290 ± 20	1 ± 0	4 ± 2	0.09
Brooks	140 ± 30	110 ± 10	4 ± 1	7 ± 2	0.57
Coville	230 ± 40	200 ± 50	8 ± 1	7 ± 1	1.75
Grosvenor	280 ± 40	280 ± 40	5 ± 2	6 ± 2	0.59
Hammersly	200 ± 40	170 ± 20	3 ± 2	6 ± 1	0.55
Kukaklek	180 ± 60	210 ± 50	3 ± 0	5 ± 1	0.97
Kulik	400 ± 40	440 ± 80	3 ± 2	5 ± 2	0.58
Murray	180 ± 20	200 ± 60	3 ± 1	6 ± 1	0.46
Naknek	240 ± 50	180 ± 30	5 ± 2	6 ± 2	0.88
Nonvianuk	270 ± 30	240 ± 40	4 ± 2	5 ± 2	0.68

collected in 1991 (Table 4), led us to believe that while the total nitrogen to total phosphorus ratio of Brooks, Naknek, Coville, and Kukaklek lakes suggested nitrogen limitation, being under 13 (Smith, 1979), the remaining lakes might be phosphorus limited since their ratios were close to or clearly above 21 (Smith, 1979).

Nutrient stimulation experiment bioassays (NSEs) were conducted successfully in Coville and Grosvenor lakes in 1992, and in Brooks, Kulik, and Nonvianuk lakes in 1993. Nitrogen limitation was reconfirmed in Brooks Lake and demonstrated in Coville Lake, but phosphorus limitation was demonstrated in Grosvenor, Kulik, and (possibly) Nonvianuk lakes (Table 7). Usually, the nutrient that was not, by itself, stimulating caused a secondary response. This was a significant additional response at both ends of Coville lake, at the western end of Grosvenor Lake, and in Brooks Lake. The secondary response of the other nutrient was not unexpected in such oligotrophic lakes that were so low in nutrients generally. However, in Kulik Lake, where phosphorus was significantly stimulating above the control, additional nitrogen caused a depression of growth alone and in combination with phosphorus.

Nitrogen limitation in some of these lakes may be caused by high phosphorus from volcanic deposits affecting their watersheds, and from the action of extensive wetlands that are sequestering or denitrifying nitrogen from inflowing water. Phosphorus limitation in other lakes likewise may be complex, caused by high nitrogen inputs and by low phosphorus availability in various proportions.

As described in the next chapter on light conditions in these lakes, total phosphorus and planktonic chlorophyll were correlated ($\rho = 0.6980$, $p = 0.0169$) and Secchi disk depth was also inversely correlated with chlorophyll-*a* ($\rho = -0.6201$, $p = 0.0418$) and with total phosphorus

Table 7. Results of nutrient stimulation bioassay experiments in lakes of Katmai National Park and Preserve, expressed as the ratio of final to initial chlorophyll *a*. Results over a continuous line are not significantly different from each other by Duncan's multiple range test. (C = control, +P = additional phosphorus added, +N = additional nitrogen added).

Brooks Lake, 1993				
Initial chl. *a*	C	+P	+N	+N&P
0.85 µg/L	0.65	0.77	1.48	2.49

Coville Lake—West, 1992				
Initial chl. *a*	C	+P	+N	+N&P
1.1 µg/L	0.82	0.73	1.49	3.24

Coville Lake—East, 1992				
Initial chl. *a*	C	+P	+N	+N&P
1.3 µg/L	0.87	0.79	1.35	2.76

Grosvenor Lake—East, 1992				
Initial chl. *a*	C	+N	+P	+N&P
1.75 µg/L	0.98	0.98	1.35	1.52

Grosvenor Lake—West, 1992				
Initial chl. *a*	C	+N	+P	+N&P
0.52 µg/L	1.53	1.57	2.40	2.80

Kulik Lake, 1993				
Initial chl. *a*	C	+N	+N&P	+P
0.86 µg/L	0.97	0.81	1.16	1.56

Nonvianuk Lake, 1993				
Initial chl. *a*	C	+N	+P	+N&P
0.62 µg/L	1.56	1.50	2.19	2.75

(ρ = -0.8913, p = 0.0002). The typical lake trophic assessment methods (Carlson, 1977) apply, and these lakes can be monitored for eutrophication by watching for decreased water clarity with the simple Secchi disk.

Carlson's (1977) equation relates total phosphorus to Secchi depth for a large data set:

$$SD = 48/TP$$

The Katmai lake data (among the 11 large lakes) produced a very similar equation:

$$SD = 46/TP$$

If the Katmai among-lakes average value of 3 mg/L total phosphorus is substituted, Carlson's equation produces a Secchi depth of 16 m and the Katmai equation 15 m. It should be noted that one implication of this empirical analysis is that a small (1 mg/L) increase in total phosphorus in the "average" Katmai lake might be associated with a relatively large reduction (to 12 m) in Secchi depth.

Light penetration depth could also be monitored since it correlates so significantly with chlorophyll (ρ = -0.7094, p = 0.0145) and with Secchi depth (ρ = 0.8372, p = 0.0013) and inversely with total phosphorus (ρ = -0.8490, p = 0.0009). However, this method of measuring water clarity is more difficult, requiring an expensive, delicate instrument and plotting and calculating of values.

Light Conditions.—Present-day lake management is often based on relationships between Secchi depth or light penetration and planktonic chlorophyll-*a* concentrations. Carlson's (1977) trophic state index for lakes relies on a relationship between Secchi disk transparency and algal biomass (as chlorophyll-*a*) and on a relationship between summer total phosphorus and chlorophyll measurements. Dillon and Rigler's (1975) model relating

allowable cottage development at Ontario lakes to selected water clarity goals relies on the above relationships, as well as ultimately on relationships between phosphorus concentrations (that would be contributed by the treated sewage) and the number of lakeside.

Recently, the light conditions of Alaska lakes were described by Koenings and Edmundson (1991) and related to water color and turbidity. Among the lakes they considered, which included clear, stained, and turbid lakes, they found phytoplankton chlorophyll not to be a useful descriptor of the light characteristics SD^{-1}, the inverse of the Secchi depth, or K_d, the coefficient of vertical attenuation. When separated into clear, stained, and turbid lakes, however, they found planktonic chlorophyll explained 59% of the variation of SD^{-1} values and 23% of the variation of K_d values among clear lakes.

For this group of 11 large, clear lakes in Katmai National Park and Preserve studied during summers 1990-1993, planktonic chlorophyll explained the majority of the variation in SD^{-1} and K_d, and neither color nor turbidity had significant relationships among lakes with these light characteristics (Table 8). While a single relationship between each of these water clarity parameters and planktonic algal chlorophyll concentrations cannot be developed for an area as large as the state of Alaska, or even as large as the area considered by Koenings and Edmundson (1991) (58 lakes in southeast and southcentral Alaska, including some on Kodiak Island), it should be possible to develop models for specific lake regions in a given geographic and physiographic setting.

The Katmai lakes were very clear and oligotrophic. Welch (1980) says Secchi depths greater than 3–5 m and chlorophyll-*a* values less than 2-4 mg/m^3 indicate the oligotrophic condition. Even Naknek Lake at the site sampled was not a turbid lake visually or comparing the turbidity value,

Table 8. Optical and water quality characteristics of lakes of Katmai National Park and Preserve, Alaska, sampled yearly in early August 1990–1993. Values are means of the average values for each of the three years (n=3) unless otherwise noted, and the range of values is beneath in parentheses.

Lake	K_d (PAR) (m^{-1})	Secchi Depth (m)	Phytoplankton[a] (mg m^{-3} chl. *a*)	Apparent Color (Pt-Co Units)	Turbidity (NTU)	Depth of 1% Light (m)
Battle	0.070	17	0.13	1.3	0.83	67
	(0.057-0.081)	(16-18)	(0.09-0.16)	(0-3)	(0.4-1.7)	(56-81)
Brooks	0.199	9.7	0.47	4	1.1	24
	(0.164-0.250)	(9.6-9.8)	(0.37-0.57)	(0-7)	(0.40-2.3)	(18-28)
Coville	0.294	5.7	1.16	7	1.2	16
	(0.260-0.349)	(4.9-6.2)	(0.56-1.75)	(0-17)	(0.83-1.7)	(13-18)
Grosvenor	0.199	10	0.52	2	0.87	23
	(0.179-0.219)	(7.8-12)	(0.45-0.59)	(0-6)	(0.60-1.4)	(21-26)
Hammersly	0.158[a]	14[a]	0.55[b]	1.5[a]	1.6[a]	30[a]
	(0.128-0.188)	(12-16)		(0-3)	(0.4-2.7)	(24-36)
Idavain	0.411[b]	4.4[b]	1.02[b]	0.0[b]	0.77[b]	11[b]
Kukaklek	0.144	13	0.63	4	0.68	34
	(0.103-0.178)	(11-16)	(0.28-0.97)	(0-10)	(0.44-1.1)	(26-45)

Table 8. Continued.

Lake	K_d (PAR) (m^{-1})	Secchi Depth (m)	Phytoplankton[a] (mg m^{-3} chl. *a*)	Apparent Color (Pt-Co Units)	Turbidity (NTU)	Depth of 1% Light (m)
Kulik	0.143	10	0.46	0.3	0.89	32
	(0.135-0.148)	(8.3-12)	(0.34-0.58)	(0-1)	(0.46-1.7)	(31-34)
Murray	0.156	13	0.34	3.7	0.66	31
	(0.108-0.183)	(10-16)	(0.23-0.46)	(0-11)	(0.29-1.2)	(25-43)
Naknek	0.210	5.3	0.69	19	1.3	23
	(0.156-0.288)	(3.2-6.5)	(0.50-0.88)	(10-33)	(0.81-1.8)	(16-29)
Nonvianuk	0.158	11	0.49	1.7	0.84	30
	(0.129-0.202)	(9.0-14)	(0.30-0.68)	(0-5)	(0.40-1.5)	(23-26)

[a] n=2; [b] n=1

Secchi depth, or light penetration coefficient to the classification of Koenings and Edmundson (1991). Phytoplankton algal biomass, as estimated by chlorophyll *a*, explained 72% ($p < 0.0006$) of the variability in the light coefficient, log K_d, and 62% ($p < 0.0023$) of the inverse Secchi depth. As expected, K_d and inverse Secchi depth were strongly correlated ($r = 0.84$, $p < 0.0008$) in this data set. Color and turbidity were not statistically related to K_d or Secchi depth.

Carlson's (1977) equation relating Secchi transparency and algal plankton biomass (as chlorophyll *a*) is:

$$\ln SD = 2.04 - 0.68 \ln chl$$

$(r = 0.93, n = 147)$

The Katmai lakes data were fitted with the equation:

$$\ln SD = 1.87 - 0.58 \ln chl$$

$(r = 0.74, n = 11)$

Substituting the overall average chlorophyll-*a* value measured for Katmai lakes, 0.6 mg/m^3, into both equations showed a similar Secchi depth of 15 m from the Katmai empirical relation to 16 m from Carlson's equation. It seemed remarkable that the Katmai equation was close to that of a much larger data set. It also should be noted that of the data used by Carlson, only 12 lakes had Secchi transparencies as high as those of the Katmai lakes. All the Katmai data are on the region of the curve where large reductions in Secchi transparency might be related to small increases in algal biomass.

The ratio of the 1% light depth to the Secchi ranged from 2.12 ± 0.18 ($\bar{x} \pm 1$ s.d.) in Hammersly Lake to 4.50 ± 0.48 in Naknek Lake (Table 9). Therefore, most of these lakes did not closely follow the "rule of thumb" that about three times the Secchi depth is the 1% light depth (Kirk, 1994).

Considering the lakes (Naknek and Battle) with high ratios of light penetration to Secchi depth, suspended sediments such as glacial flour in

Table 9. Hybrid optical characteristics of lakes of Katmai National Park and Preserve, Alaska, sampled yearly in early August 1990–1993. Values are from means of the values for the three years.

Lake	1% Depth:SD	% PAR @ SD
Battle	3.9	30.1
Brooks	2.5	15.4
Coville	2.9	19.6
Grosvenor	2.3	13.9
Hammersly	2.1	11.7
Idavain	2.5	16.4
Kukaklek	2.7	18.1
Kulik	3.2	23.1
Murray	2.4	14.4
Naknek	4.5	35.9
Nonvianuk	2.7	18.4

Naknek Lake may be a source of tripton of the proper size to efficiently scatter light and reduce SD, while light penetration is less affected. Battle Lake, however, was so brilliantly clear and blue that it looked like cobalt glass when the sun was shining. The K_d of Battle Lake is very close in value to the 0.060 of Crater Lake, Oregon, which is considered to be one of the clearest lakes in the U.S. Crater Lake often has a Secchi depth of about 40 m (Cole, 1994), while Battle Lake Secchi depth was less than half that deep. In Battle Lake, it is possible that bacteria or ultraplankton of about 1 μm in size may be of the proper concentration and refractive index to participate in intense light scattering. Since these small particles scatter mostly in the forward direction, at small angles to the light beam (Kirk, 1994), light penetration to great depth in these lakes is not very affected by the scattering that, however, occludes the Secchi disk.

A comparison of the light conditions from the upper end of Coville Lake to the lower, and then into Grosvenor Lake from the upper to lower end, showed that the slightly low relationship between light penetration and the Secchi depth was about the same (closer to 2 than 3 times) along that part of the Naknek River drainage (Table 10). However, the measurement of the light penetration coefficient, K_d, fell to about half the value of Coville Lake in the upper basin of Grosvenor Lake, and the Secchi depth and 1% light depth correspondingly doubled. These differences between the adjacent basins of the two lakes were undoubtedly due to the effects on light caused by planktonic algae. Average chlorophyll-*a* concentrations were twice as high in the lower basin of Coville Lake as in the upper basin of Grosvenor Lake during the 1992 synoptic lake survey (Table 6).

Since this study was conducted to set a water quality baseline that the National Park Service will monitor, probably using non-limnologists, the recommendation is made that they use a Secchi disk to monitor water clarity

Table 10. Light measurements along a transect through Coville and Grosvenor lakes, August 3, 1992.

Lake	K_d (PAR) (m^{-1})	Secchi Depth (m)	Depth of 1% Light (m)	1% Depth:SD	% PAR @ SD	K_d·SD
Coville (West)	0.390	6.5	11.8	1.8	8.2	2.5
Coville (East)	0.349	6.2	13.2	2.1	11.1	2.2
Grosvenor (West)	0.172	13.1	26.8	2.0	11.1	2.2
Grosvenor (East)	0.219	11.1	21.0	1.9	9.1	2.4

in Katmai Park lakes. This study found high interannual variability in Secchi depth—decreasing up to 5 m in Kukaklek and Nonvianuk lakes and 6 m in Murray Lake between 1990 and 1991, but increasing again in 1992 (Appendix E). A constant decreasing trend in Secchi depths in any of these lakes that continues more than 5 years in a row should be investigated by a limnologist, who should measure phytoplankton standing crop, color, and turbidity to assess the cause of the decreased clarity.

Zooplankton.—On July 27, 1992, repeated sampling of Coville and Grosvenor lakes at two locations each, hauling the net vertically from multiple depths, showed that zooplankton were uniformly distributed in the whole water column of these lakes (Table 11). While that did not prove that uniform distribution was true on every sampling date in every lake, it was reassuring that hauling the net from the bottom of the lake to the surface was probably not incorrect technique. Had all the zooplankton been concentrated near the surface of the lake during the daylight hours, dividing by the volume of water that passed through the net would have given progressively lower than true concentrations, the deeper the sampling haul. Crustacean zooplankton are also found to be relatively evenly distributed through the whole water column in the deep, subarctic lake Thingvallavatn, Iceland, in a long-term study (Jonasson, 1992). The adult zooplankton species there do migrate to the near surface at night, but the migration of the adults does not change the overall distribution because of the importance of distribution of juveniles in the population (Antonsson, 1992).

Zooplankton concentrations were lowest (Table 12) in 1991 of the three synoptic lake surveys. This is apparently not explained by laboratory technique. In all 3 years, samples were all brought up to 100 mL by adding water. In 1990 a 5-mL subsample was filtered and mass multiplied by 20. In

Table 11. Zooplankton standing crop as ash-free dry weight at two locations and various depths—Coville and Grosvenor lakes, July 27, 1992.

Lake	Haul Depth (m)	Sample Ash-free Dry Weight (mg/m^3)	Lake Average (±1 SD) Ash-free Dry Weight (mg/m^3)
Coville *	25	31.89	
(East)	25	30.14	29.6 ± 2.2
	50	29.82	
	50	26.59	
Coville	5	23.50	
(West)	5	23.04	
	10	33.41	
	10	28.57	28.0 ± 4.4
	15	28.11	
	15	34.56	
	20	29.03	
	20	23.62	
Grosvenor	30	18.74	
(East)	30	15.44	
	40	24.37	17.6 ± 4.6
	40	22.35	
	40	11.23	
	60	16.21	
	60	14.52	

Table 11. Continued.

Lake	Haul Depth (m)	Sample Ash-free Dry Weight (mg/m^3)	Lake Average (±1 SD) Ash-free Dry Weight (mg/m^3)
Grosvenor *	20	49.54	
(West)	20	40.21	
	40	27.94	33.2 ± 10.0
	40	31.11	
	60	28.46	
	60	22.04	

* Denotes the site of the synoptic survey (Figure 1).

Table 12. Lake standing crop of zooplankton and the depth of the haul of the net—Katmai National Park and Preserve.

Lake	1990		1991		1992	
	Ash-free Dry Weight (mg/m^3)	Haul Depth (m)	Ash-free Dry Weight (mg/m^3)	Haul Depth (m)	Ash-free Dry Weight (mg/m^3)	Haul Depth (m)
Battle	< 2	50	< 1	40	1.1	58
Brooks	44	55	11	19	45	28
Coville	48	24	25	28	30	50
Grosvenor	31	55	10	50	33	60
Hammersly	— [a]	—	5	23	14	35
Idavain	499	9.5	—	—	—	—
Kukaklek	98	60	6	50	39	28
Kulik	12	65	1	75	5.4	50
Murray	45	32	4	10	12	30
Naknek	28	50	3	50	32	21
Nonvianuk	—	—	11	25	88	32

[a] Dash indicates missing data.

1991 half of the sample was filtered onto each of two filters and the mass of both was summed. In 1992 the entire sample was filtered through a single filter. These differences in technique did not explain the generally lower values of zooplankton biomass in 1991. These lower values may have been the result of colder weather, which can be seen in the lake thermal profiles for that year (e.g., see Figures 12, 13, and 15).

When the average zooplankton biomass values at each lake (usually for 3 years, except 1 year for Idavain Lake and 2 for Hammersly and Nonvianuk lakes) were calculated, they varied among lakes with planktonic algal biomass ($\rho = 0.6273$; $p = 0.0388$). This was expected because zooplankton rely on the small plankton algae (nannoplankton) for food (McCauley and Kalff, 1981). When the biomasses of algae and zooplankton are both expressed as organic mass (ash-free dry weight) by multiplying the chlorophyll by 67 (APHA et al., 1989) (Table 13), the zooplankton mass in a lake was sometimes estimated higher than the algal mass (Brooks, Idavain, Kukaklek, and Nonvianuk lakes). It is interesting to note that besides Idavain and Murray lakes, where sockeye do not reproduce (Buck et al., 1978), all the other lakes with apparent inverted pyramids of trophic-level standing crops are important nursery lakes for sockeye salmon. Inverted mass of trophic levels occurs when zooplankton grazing is intense (Goldman and Horne, 1983). They are also common in oligotrophic lakes (like the Katmai lakes) because the microbial loop is also providing zooplankton food. The microbial bacteria and nannoplankton that process detritus pass through the filters commonly used to measure phytoplankton biomass (Horne and Goldman, 1994).

Zooplankton standing crop also varied inversely with lake barium concentration ($\rho = -0.7244$; $p = 0.0017$). Whether or not the zooplankton were affected by barium cannot be said; experiments would have to be run to

Table 13. Mean biomass of planktonic algae and zooplankton—Katmai lakes, 1990-92.

Lake	Algal Plankton		Zooplankton
	mg/m^3 (as chl. *a*)	mg/m^3 (calculated as ash-free dry weight)	mg/m^3 (as ash-free dry weight)
Battle	0.13	8.7	< 2.
Brooks	0.47	32.	33.
Coville	1.16	78.	34.
Grosvenor	0.52	35.	25.
Hammersly	0.55	37.	10.
Idavain	1.02	68.	499.
Kukaklek	0.63	42.	48.
Kulik	0.46	31.	6.0
Murray	0.34	23.	20.
Naknek	0.69	46.	21.
Nonvianuk	0.49	33.	50.

deduce its toxicity, if any. There are no water quality criteria for protection of aquatic life for barium.

Streams

Hydrology.—Streams measured in 1990 varied from large (530 ft^3/sec, Table 14) to small (2 ft^3/sec, Table 15) where sampled. The upper Alagnak River (Figure 1) was too deep to attempt a discharge measurement, and the Savonoski River was only partially cross-sectioned because of unwadeable depths.

Among the streams sampled, turbidity correlated strongly with suspended sediment measurements ($\rho = 0.8201$, $p = 0.0000$) (Tables 16 and 17). Suspended sediments could not be run in Brooks Lake inlets in 1992 because the pre-ignited filters were mistakenly relabeled by the NPS assistants. Streams still affected by the 1912 volcanic eruption (the Savonoski and Ukak rivers) carry large amounts of suspended sediments that exert high turbidity (Table 16).

Major Ions.—Data for streams were fewer than those for lakes. Most streams were only sampled once (1990) when Park staff attempted to sample the major streams of the Naknek and Alagnak drainages (Figure 1), including all the major inlets to Battle Lake (Figure 2) and to Brooks Lake (Figure 3). The Brooks Lake inlets were sampled again in 1991 when there was a historically high run of sockeye salmon to these inlets because of the Bristol Bay commercial fishers' strike. Those Brooks Lake inlets were sampled again in 1992 as a success-of-training exercise for NPS staff members. Therefore, because the stream data set was limited, and the variability of replicate samples was high, it was not possible to fully characterize the streams of the two watersheds.

Table 14. Hydrology of selected streams of Katmai National Park and Preserve, August and September 1990.

Stream	Velocity (ft/sec)	Width (ft)	Discharge (ft^3/sec)
Alagnak Drainage			
Battle 1	3.2	23.8	48
Battle 2	1.2	121.	238
Battle 3	1.4	44.	64
Battle 4	2.1	7.6	10
Battle 5	3.0	15.5	32
Battle River	1.6	192.	400
Alagnak River	—[a]	—	—
Naknek Drainage			
American Creek	1.3	181.	530
Brooks River	2.1	155.	386
Margot Creek	1.9	128.	210
Savonoski River	—	279.[b]	> 359[c]
Ukak River	2.1	17.8	31

[a] Dash indicates no data taken.

[b] Wadeable width.

[c] Discharge for 279-ft width that was wadeable.

Table 15. Hydrology of Brooks Lake inlet streams, Katmai National Park and Preserve.

Stream	Velocity (ft/sec)	Width (ft)	Discharge (ft^3/sec)
1990			
Brooks 2	0.4	25.1	9
Brooks 3	0.8	22.2	19
Brooks 4	1.13	113	265
Brooks 5	0.8	7.7	3
Brooks 6	2	10.1	13
Brooks 7	0.7	9.5	2
1991			
Brooks 2	1.04	20.9	25
Brooks 3	0.83	27.2	10
Brooks 4	— *	—	—
Brooks 5	1.34	11.3	12
Hidden Creek	1.16	15.4	13
1992			
Brooks 2	1.43	22.1	29
Brooks 3	0.98	26.4	21
Brooks 4	—	—	—
Brooks 5	1.03	6.5	18
Hidden Creek	1.41	15.4	18
Cat Creek	1.19	3.3	2

* No data taken.

Table 16. Sediment characteristics of selected streams of Katmai National Park and Preserve, August and September 1990 (mean value ± CI, n=3).

Stream	Turbidity (NTU)	Suspended Solids (mg/L)
Alagnak Drainage		
Battle 1	0.9 (± 1.3)	1.5
Battle 2	0.6 (± 1.2)	2.0 (± 1.8)
Battle 3	0.3 (± 0.2)	4.9 (± 3.4)
Battle 4	0.6 (± 2.0)	2.7 (± 1.1)
Battle 5	0.3 (± 0.1)	2.4
Battle River	0.2 (± 0.1)	3.1 (± 2.8)
Alagnak River	2.1 (± 1.2)	9.4 (± 28.2)
Naknek Drainage		
American Creek	2.4 (± 2.9)	25.0 (± 20.7)
Brooks River	— *	5.0 (± 8.2)
Brooks 2	1.9 (± 0.3)	2.2 (± 1.7)
Brooks 3	0.6	0.1
Brooks 4	2.6 (± 2.8)	0.2
Brooks 5	0.9 (± 0.6)	0.5
Brooks 6	1.9	5.2 (± 14)
Brooks 7	0.5 (± 0.2)	4.1 (± 1.9)
Margot Creek	—	10.5 (± 24.5)
Savonoski River	123 (± 47)	226.7 (± 112.7)
Ukak River	210 (± 412)	665.0 (± 528.2)

* Dash indicates no data taken.

Table 17. Inlet stream sediment characteristics, Brooks Lake, 1991 (mean values ± 1 SD, n=3).

Streams (Creeks)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Fixed (Inorganic) Suspended Solids (mg/L)	Volatile (Organic) Suspended Solids (mg/L)
Brooks 2	19 ± 1	39.3 ± 0.2	33.9 ± 0.84	5.4 ± 1.0
Brooks 3	6.0 ± 0.9	27.6 ± 5.1	22.5 ± 4.06	5.1 ± 1.0
Brooks 4	9.7 ± 3.5	12.4 ± 3.5	12.0 ± 7.0	2.8 ± 0.4
Brooks 5	0.70 ± 0.05	1.58 ± 1.00	0.51 ± 0.91	1.1 ± 0.3
Hidden Creek	3.2 ± 0.3	17.9 ± 6.3	13.7 ± 5.02	4.2 ± 1.3

In general, the average concentrations of each of the major ions were higher among streams than among lakes of this area. When inlets of Brooks and Battle lakes were considered (Tables 18-20), usually the lake was near the middle of the range of inlet concentrations for each particular ion. Of all the streams sampled in 1990, the Ukak River, a tributary of Naknek Lake, had the highest ion sum at 6.44 meq/L and Battle Inlet #3 the lowest at 0.48 meq/L (Appendix C). Only the Ukak and Savonoski rivers exceeded the world average ion sum of 2.853 meq/L (Wetzel, 1983).

Three of the inlets to Battle Lake (1, 2, and 3) had no titrable bicarbonate alkalinity, and inlet 5 had about 2% bicarbonate alkalinity (Table 18) based on its total anions (as meq/L). The other Battle Lake inlet sampled (4) had about equal proportions of bicarbonate alkalinity and sulfate but was dominated by chloride, as were all the other Battle Lake inlets except 1, Iron Springs Creek, which was dominated by sulfate. As mentioned before, Battle Lake was also dominated by sulfate, but the outlet, Battle River, was dominated by chloride (Table 18). While these findings were not conclusive because they were based on one sampling event, they call attention to the fact that particular inlets may have a strong influence on a lake locally, and some of these lakes are impossible to characterize chemically at a single sampling station, even though the particular lake may have only a single basin. Color was higher in Brooks Lake streams in 1991 (Table 19) compared to 1992 (Table 20). This may have been due to decomposition of the large runs of sockeye salmon in 1991 in those streams. The higher chloride values of 1991 (Table 19) than of 1992 (Table 20) were probably due to higher precipitation of sea salt due to weather in 1991.

Among streams sampled, the cations grouped closely together in a ternary plot of proportions (as meq/L) (Figure 21), but the anions were widely spread in groups associated by location on the landscape (Figure 22).

Table 18. Physical and chemical characteristics of selected streams of Katmai National Park and Preserve, August and September 1990.

Stream	Temperature (°C)	pH	Conductivity (µS/cm)	HCO_3^- (mg/L as $CaCO_3$)	$SO_4^=$ (mg/L)	Cl^- (mg/L)
Alagnak Drainage						
Battle 1	9.0	4.4	120	0.0	18.3	9.4
Battle 2	11.0	6.6	29	0.0	6.0	7.4
Battle 3	12.5	7.0	39	0.0	3.7	7.6
Battle 4	9.0	6.9	20	5.5	4.7	7.5
Battle 5	9.0	7.2	71	0.6	17.7	8.0
Battle River	10.5	7.3	180	5.4	6.7	8.2
Alagnak River	—	7.2	43	12.9	3.7	5.8
Naknek Drainage						
American Creek	9.2	7.3	76	35.4	2.5	6.8
Brooks River	10.0	7.5	53	27.0	6.0	5.8
Brooks 2	— *	8.0	162	64.1	8.3	7.4
Brooks 3	7.0	7.7	66	30.4	22.0	9.7

Table 18. Continued.

Stream	Temperature (°C)	pH	Conductivity (µS/cm)	HCO_3^- (mg/L as $CaCO_3$)	$SO_4^=$ (mg/L)	Cl^- (mg/L)
Brooks 4	9.0	7.5	86	34.2	12.3	4.7
Brooks 5	9.5	7.8	78	45.1	6.3	4.1
Brooks 6	—	7.7	118	37.6	1.0	5.2
Brooks 7	—	7.7	97	70.3	4.7	8.0
Margot Creek	6.8	7.5	71	32.3	13.0	5.6
Savonoski River	8.5	7.7	150	35.7	25.0	7.7
Ukak River	9.5	7.8	270	50.5	70.0	26.8

Table 19. Physical and chemical characteristics of Brooks Lake inlet streams, 1991. Means ± 1 SD.

Stream	Color (units)	Temperature (°C)	pH	Conductivity (µS/cm)	HCO_3^- (mg/L as $CaCO_3$)	$SO_4^=$ (mg/L)	Cl^- (mg/L)
Brooks 2	19 ± 2	7.7	7.75	136.	46.7 ± 0.4	16 ± 0	21 ± 4
Brooks 3	18 ± 4	5.7	7.50	87.7	31.9 ± 0.3	0	25 ± 1
Brooks 4	40 ± 2	7.6	7.21	84.2	29.2 ± 0.2	0	19 ± 1
Brooks 5	20 ± 5	12.1	5.78	98.7	37.5 ± 0.0	0	13 ± 2
Hidden Creek	18 ± 2	7.4	7.46	116.	42.4 ± 0.2	0	23 ± 5

Table 20. Physical and chemical characteristics of Brooks Lake inlet streams, 1992.

Stream	Color (units)	Temperature (°C)	pH	Conductivity (µS/cm)	HCO_3^- (mg/L as $CaCO_3$)	$SO_4^=$ (mg/L)	Cl^- (mg/L)
Brooks 2	2 ± 1	8.1	5.70 [a]	118	55.3 ± 8.5	15 ± 10	2.2 ± 0.3
Brooks 3	0	6.9	5.73	80	28.9 ± 5.0	0	1.8 ± 0.3
Brooks 4	3 ± 0	9.1	5.97	75	34.9 ± 5.0	0	2.3 ± 0.2
Cat Creek	4 ± 1	9.0	6.33	113	47.6 ± 5.5	0.3 ± 0.6	3.0 ± 0.3
Hidden Creek	1 ± 1	8.7	6.43	93	3.50 ± 5.8	0	2.3 ± 0.2

[a] Low values probably due to probe malfunction.

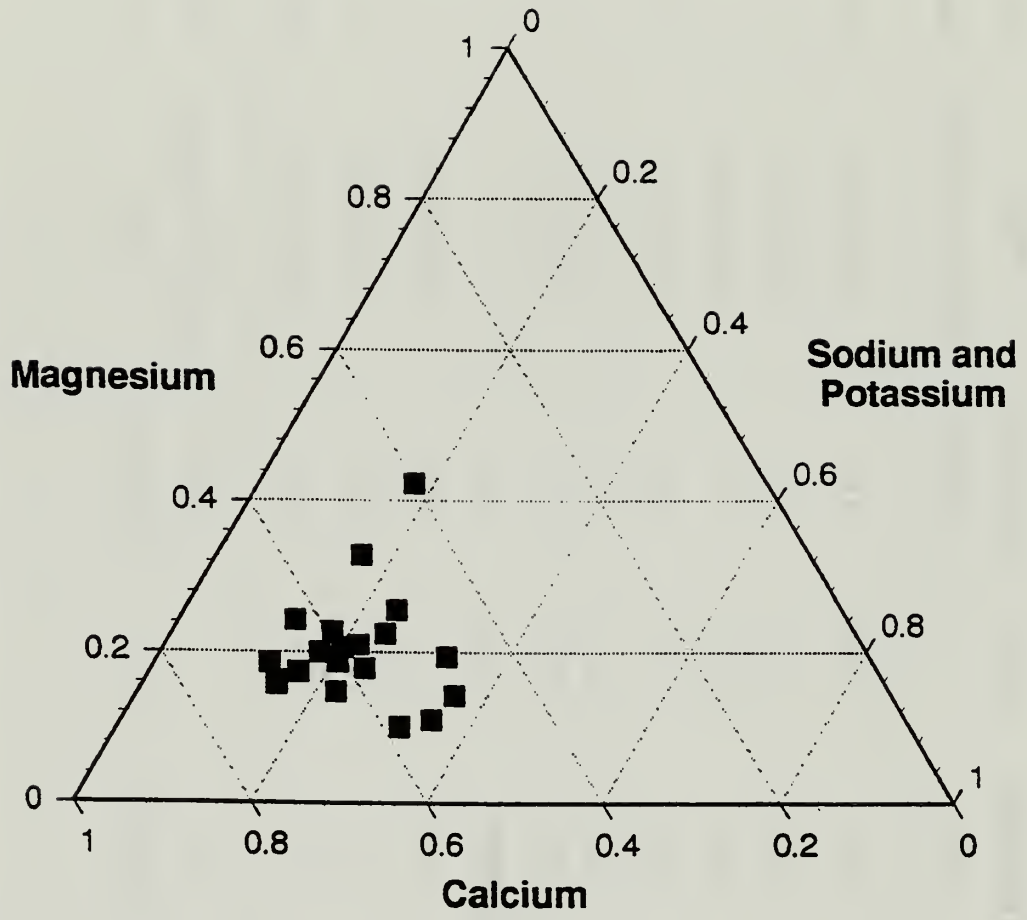

Figure 21. Ternary diagram of the major cations of streams of Katmai National Park and Preserve, 1990. The top point is for Kulik Inlet #8, the apparent warm spring, and Iron Springs Creek Creek, Inlet #1 at Battle Lake, is immediately under it.

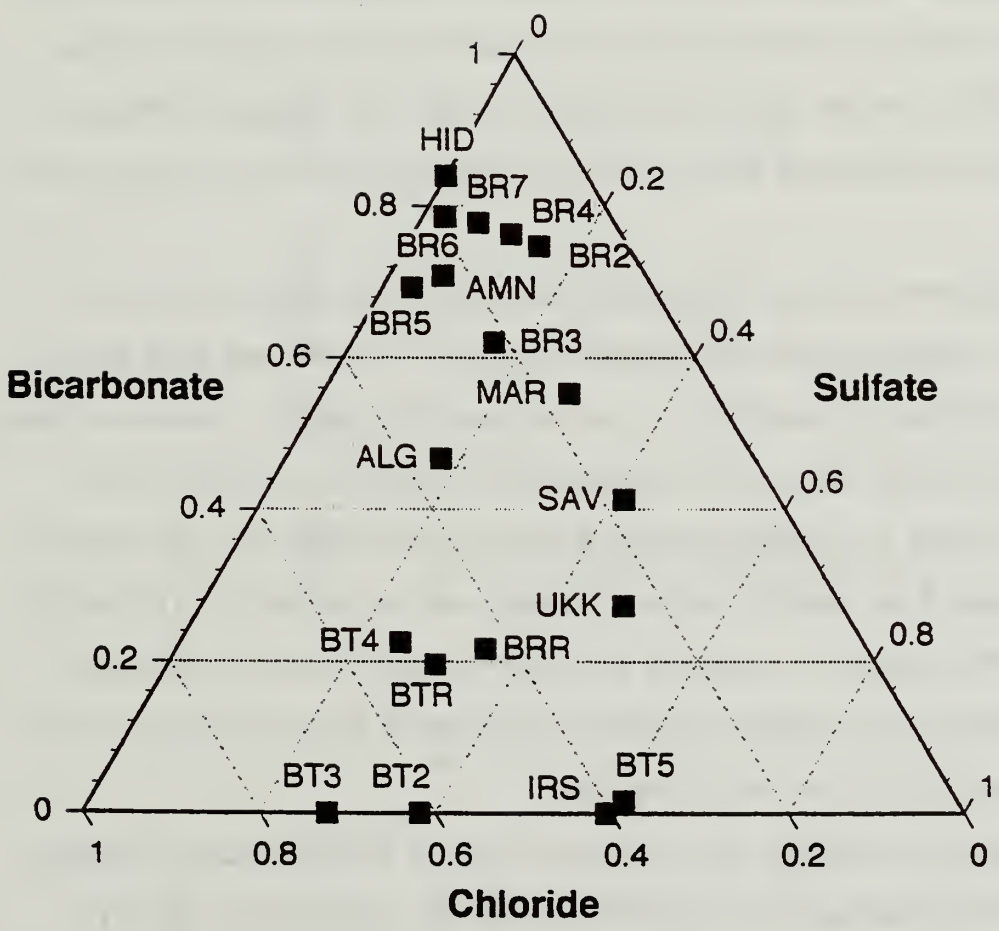

Figure 22. Ternary diagram of the major anions of streams of Katmai National Park and Preserve. (ALG=Alagnak River, AMN=American Creek, BRR=Brooks River, BTR=Battle River, BR#=Brooks Lake inlets by number, BT#=Battle Lake inlets by number, HID=Hidden Creek at Brooks Lake, IRS=Iron Springs Creek at Battle Lake, MAR=Margot Creek, SAV=Savonoski River, and UKK=Ukak River). Values are averaged across years if the stream was sampled more than once.

The inlets to Brooks Lake and American Creek, which is at the top of the Naknek drainage, clustered at the top of the anion diagram because they tend to be dominated by bicarbonate. The relatively low pH values of 1992 Brooks Lake inlets (Table 20) were probably due to probe malfunction. The Battle Lake inlets spread across the bottom because of their chloride and sulfate dominance, and the inlets of Naknek Lake (the Brooks, Ukak, and Savonoski rivers and Margot Creek) grouped together at the center. The Alagnak River, at the outlet of Nonvianuk Lake in the Alagnak drainage, was somewhat separated from the Battle Lake inlets and outlet, being more alkaline.

Additional inlets of Kulik and Nonvianuk lakes (Figures 3 and 4) were only sampled for anions (Tables 21 and 22) in 1992 and were high or low in proportion of chloride, but not moderate (Figure 23). Therefore, these inlets of both lakes were grouped along either side of the ternary anion diagram (Figure 23), spread according to their proportion of bicarbonate or sulfate. Kulik Lake inlet 8, sampled for both anions and cations (Appendix D3) in 1992, which was probably discharging water from a geothermal spring, plotted at the bottom rightmost in the anion diagram (Figure 23), as well as at the top of the cation diagram.

Among the streams with both major cation and anion data, calcium varied with magnesium ($\rho = 0.8367$; $p < 0.0000$), sodium ($\rho = 0.8767$; $p < 0.0000$), and bicarbonate ($\rho = 0.7541$; $p < 0.0001$). Magnesium was also related to sodium ($\rho = 0.9406$; $p < 0.0000$) and bicarbonate ($\rho = 0.8256$; $p < 0.0000$), but not to chloride ($\rho = 0.0960$; $p = 0.6874$). Therefore, while one source of sodium chloride to these streams was probably precipitation, there may have been a rock or soil source of sodium bicarbonate as well.

Table 21. Physical and chemical characteristics of Kulik Lake inlets, 1992.

Streams	Estimated Q (m^3/sec)	Temperature (°C)	pH	Conductivity (µS/cm)	HCO_3^- (mg/L as $CaCO_3$)	$SO_4^{=}$ (mg/L)	Cl^- (mg/L)	NO_3^-/NO_2^- – N (mg/L)
Kulik Lake Inlet								
1	4	7.6	6.77	58	11.4	14.	< 0.1	0.07
2	10	5.6	7.04	17.4	— [a]	—	—	—
3	10	6.7	7.00	13.0	—	—	—	—
4	45	6.2	7.16	15.0	2.6	0	< 0.3	0.09
5	25	6.2	7.00	15.0	—	—	11.8	—
6	40	6.6	7.26	16.4	3.9	0	< 0.3	0.07
7	50	7.6	7.17	44.2	11.0	12.	12.5	0.10
8 [b]	4	15.6	6.78	416.0	16.3	195	< 0.6	—
9	15	8.9	7.60	39.0	—	—	—	—
10	1	6.3	7.61	48.3	—	—	—	—
11	—	13.8	7.48	41.0	17.3	0	—	—

[a] A dash indicates test not run.

[b] This stream is from an apparent hot or warm spring.

Table 22. Chemical characteristics of Nonvianuk Lake inlets, 1992.

Inlet	Color (units)	Anions			
		HCO_3^- (mg/L as $CaCO_3$)	$SO_4^=$ (mg/L)	Cl^- (mg/L)	NO_3^-/NO_2^- (mg/L)
1	20	24.3	0	≤ 0.5	0.15
2	56	25.4	0	12	0.08
3	54	18.0	0	14	0.11
4	21	16.9	0	10	0.06

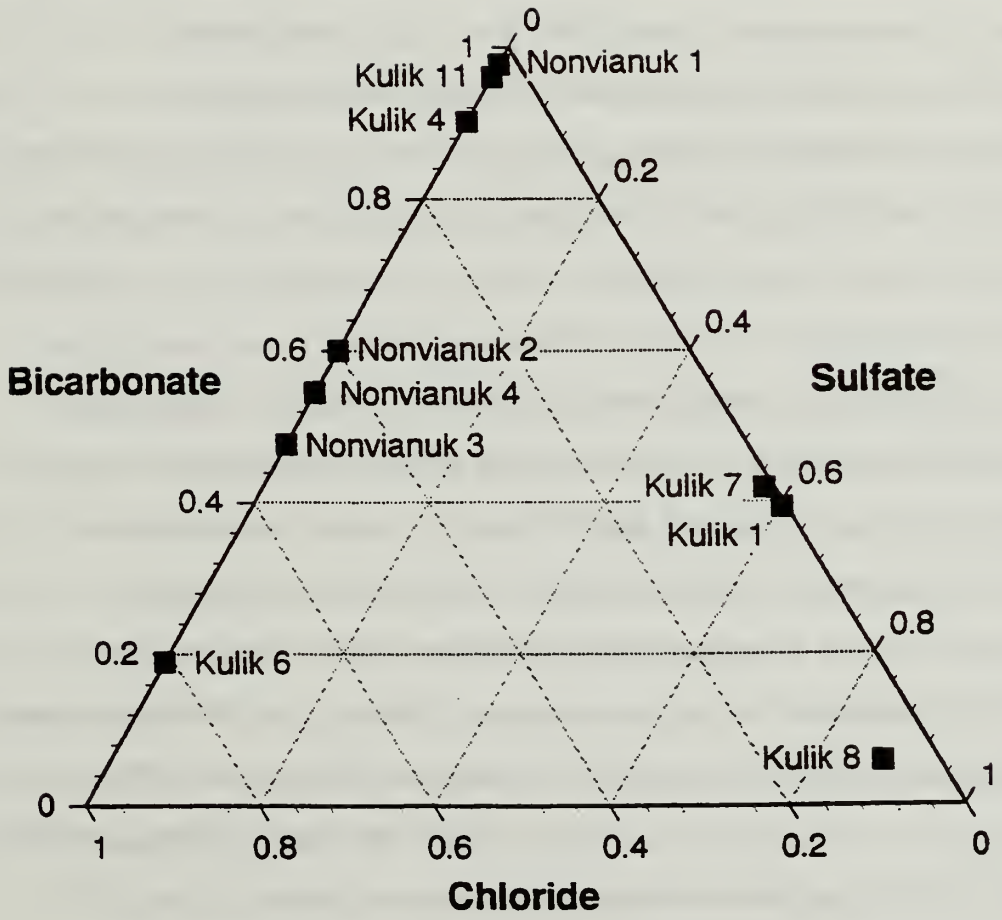

Figure 23. Ternary diagram of the major anions of inlet streams of Kulik and Nonvianuk lakes, Katmai National Park and Preserve.

Trace Elements.—Relatively few samples of streams were taken and analyzed by ICP. In general, all elements measured had higher concentrations in streams (Appendix D) than in lakes (D. Hawkins. 1995. Emeritus Professor of Geology and Geochemistry, University of Alaska Fairbanks, personal communication).

Among the streams, iron and silicon again varied with calcium ($\rho = 0.7537$; $p = 0.0001$, and $\rho = 0.8180$; $p = 0.0000$, respectively), but iron also varied with manganese ($\rho = 0.7893$; $p = 0.0000$) and silicon ($\rho = 0.8597$; $p = 0.0000$). Manganese also varied with magnesium ($\rho = 0.7858$; $p = 0.0000$) and silicon with calcium ($\rho = 0.8180$; $p = 0.0000$) and sodium ($\rho = 0.8180$; $p = 0.0000$). Strontium, as in lakes, varied with conductivity, but for streams, barium varied with manganese ($\rho = 0.8230$; $p = 0.0000$). Aluminum in streams (which can be toxic) was measured at least once (1990) in American Creek, the Battle Lake inlets (particularly inlet 1, Iron Springs Creek), on the east side of Brooks Lake, and at high concentrations in the Savonoski and Ukak rivers, where even the acute freshwater criterion for the protection of aquatic life was apparently exceeded, as it was in Iron Springs Creek. Other lower values may have exceeded the freshwater chronic criterion for aluminum in 1990 in the other inlets of Battle and Brooks lakes and in American and Margot creeks, but exceedances were confirmed by measuring more than once (1990 and 1991) only on Up-a-Tree and Headwaters creeks, inlets of Brooks Lake.

Boron was high (0.17 mg/L) in the Ukak River, undoubtedly due to volcanic springs. The Ukak River is influenced by the waters of the Valley of Ten Thousand Smokes, where the volcanic eruption occurred in 1912. Copper and lithium (another volcanic indicator) were also measurable in the Savonoski and Ukak rivers. Titanium was measurable in American, Headwaters, and Margot creeks in 1990 and highly elevated in the

Savonoski and Ukak rivers. It is a common element in igneous (volcanic source) rocks. The Savonoski and Ukak rivers also had ICP-measurable phosphorus, probably associated with the heavy suspended sediments, as did Up-a-Tree Creek in 1991 (Appendix D) during the unusually high salmon run to Brooks Lake.

Zinc also appeared measurable in the Battle River and Battle inlets 1 (Iron Springs Creek), 2, 4, and 5 in 1990 and perhaps in some of the inlets to Brooks Lake. However, zinc was not found measurable in Brooks Lake inlets that were resampled in 1991. This lack of confirmation in the second year reinforced the idea that more sampling would have to be conducted to describe the trace element conditions of streams of Katmai Park and Preserve.

Nutrients.—Of the Brooks Lake inlet streams sampled in each of the 3 years for total phosphorus and total nitrogen, Headwaters Creek (Brooks 4) had the most and Up-a-Tree Creek (Brooks 2) second most. Both total nitrogen and total phosphorus were elevated in 1991 in these inlets when a record run of sockeye salmon returned to the lake due to a commercial fishers' strike in Bristol Bay. Discharge was higher in 1992 than in 1991, but higher in 1991 than in 1990, so low discharge does not explain the peaking of nutrients in these streams in 1991.

Phosphorus is known to strongly adsorb to sediments (Wetzel, 1983). Not surprisingly, therefore, among the Katmai streams sampled, turbidity was correlated to total phosphorus measurements ($\rho = 0.8488$; $p = 0.0000$) (Tables 23–25). However, as is usual in clearwater, subarctic streams (LaPerriere, 1983), total phosphorus was strongly correlated with sestonic (suspended) algae as chlorophyll measurements ($\rho = 0.7817$; $p = 0.0000$).

Table 23. Sestonic algal and total phosphorus characteristics of selected streams of Katmai National Park and Preserve, August and September 1990. (Mean ± 95% CI).

Stream	Sestonic Chlorophyll *a* (mg/L)	Total Phosphorus (µg/L)
Alagnak Drainage		
Battle 1	0.21	≤ 3.0
Battle 2	1.06	≤ 3.0
Battle 3	0.34	≤ 3.0
Battle 4	≤ 0.07	1.9 (± 3.3)
Battle 5	0.73	11.4
Battle River	0.29	≤ 3.0
Alagnak River	1.08	1.52 (± 0.8)
Naknek Drainage		
American Creek	0.80	67.6 (± 5)
Brooks River	0.38	11.4 (± 10.8)
Brooks 2	1.25	29.1 (± 5.4)
Brooks 3	0.91	≤ 3.0
Brooks 4	1.38	62.4 (± 7.9)
Brooks 5	0.28	4.29 (± 1.42)
Brooks 6	0.41	15.2 (± 2.1)
Brooks 7	0.24	2.4 (± 4.1)
Margot Creek	0.40	12.4 (± 3.6)
Savonoski River	1.22	74.3 (± 4.3)
Ukak River	2.44	99.1

Table 24. Nutrient characteristics (μg/L) of Brooks Lake inlet streams, 1991. (Mean ± 1 SD).

Stream	Total P	Total Dissolved P	Total N	Total Dissolved N
Brooks 2	39 ± 22	14 ± 1	355 ± 62	211 ± 14
Brooks 3	23 ± 12	11 ± 0	272 ± 49	185 ± 29
Brooks 4	42 ± 2	26 ± 1	681 ± 38	521 ± 16
Brooks 5	8 ± 1	15 ± 8	242 ± 31	246 ± 76
Hidden Creek	21 ± 2	13 ± 1	149 ± 20	181 ± 25

Table 25. Turbidity, sestonic algal, and nutrient characteristics of Brooks Lake inlet streams, 1992. (Mean ± 1 SD).

Streams	Sestonic Chlorophyll *a* (mg/L)	Turbidity (units)	TP (µg/L)	PO_4^{-3} (mg/L)	TN (µg/L)	NO_3^-/NO_2^- – N (mg/L)
Brooks 2	0.76	4 ± 2	26 ± 1	0.25 ± 0.22	280	0.04 ± 0.01
Brooks 3	0.38	1 ± 1	10 ± 1	0.07 ± 0.03	160	0.06 ± 0.01
Brooks 4	0.40	2 ± 1	46 ± 1	0.08 ± 0.03	520	0.06 ± 0.00
Brooks 5	0.45	0.6 ± 1.1	10 ± 5	0.05 ± 0.00	240	0.04 ± 0.01
Hidden Creek	0.77	2 ± 2	15 ± 1	0.07 ± 0.03	220 ± 4	0.06 ± 0.00
Cat Creek	2.12	1 ± 1.2	15 ± 0	0.05 ± 0.00	520 ± 100	0.08 ± 0.01

The significant correlations of chlorophyll measurements of sestonic algae in these streams (Tables 23–25) with suspended solids ($\rho = 0.6544$; $p = 0.0024$) and with turbidity ($\rho = 0.6508$; $p = 0.0034$) were perhaps surprising. However, this is not unusual in clearwater streams where the majority of the suspended material that exerts turbidity can be dislodged benthic algae.

Scientific Findings

Lakes

- The large lakes of Katmai National Park and Preserve do not develop persistent summer temperature stratification because of the coastal weather with frequent windy storms. Therefore, fish growth is likely enhanced because of the large water volume that becomes warmed, and because living phytoplankton is probably not sedimented to the lake bottoms but circulated upwards through the algal growth zone during wind-mixing events.
- Oxygen profiles were orthograde; therefore, all these lakes were judged oligotrophic.
- Despite low alkalinity in some of these lakes, pH measurements were all close to neutral. The only acidic profile (~ 6) was measured in Battle Lake, which has the lowest alkalinity (0.04 meq/L). This profile may have been influenced by nearby Iron Springs Creek, which has been measured with a pH of 4.4.
- Specific conductivity was moderate in these lakes and decreased with depth, except for some profiles of Battle Lake where it increased with depth. The increased salinity at depth was probably due to proximity to inlets that were acidic and metalliferous.

- Except for sulfate and chloride, the concentrations of all the major ions varied inversely with altitude among the lakes.
- The lakes all had similar proportions of cations, in which calcium dominated, followed by magnesium and sodium in nearly equal proportion. Sodium is somewhat overrepresented compared to "world average" lakes because of proximity of this area to the influence of the sea. Potassium represented ≤ 1% of the total cations in each lake.
- Brooks, Coville, Grosvenor, Hammersly, Idavain, Murray, and Nonvianuk lakes were typical bicarbonate lakes when anions were considered. Kukaklek might be called a chloride-bicarbonate lake and Naknek a sulfate-bicarbonate lake. Kulik Lake had equal proportions of all three major anions, a condition geochemists call "triple water."
- Battle Lake was found to be of an unusual type, dominated by sulfate at about 71% of the major anions.
- Chloride is overrepresented in some of these lakes due to proximity to the sea, but high sulfate may be from geothermal sources in Naknek and Kulik lakes, as well as from weathering of reduced sulfur rock sources, which may be the dominate source in Battle Lake.
- All four lakes in the Alagnak drainage are acid sensitive, as shown by the ratio of alkalinity to calcium plus magnesium. Battle Lake has an extraordinarily low ratio of 0.2—pristine lakes, even in areas where sulfur minerals are weathering, seldom have ratios less than 0.6.
- Boron was measurable in Naknek Lake, probably contributed by volcanic waters. Strontium concentrations among lakes varied inversely with altitude and with conductivity and its correlates; therefore, it probably has a natural, geologic source.
- Aluminum exceeded the method detection limit in Battle Lake in all three synoptic surveys. This condition was probably due to the low alkalinity

and high sulfate concentrations of the lake. The aluminum concentrations there appear to exceed the freshwater chronic criterion for the protection of aquatic life.

- Total phosphorus was very low in these lakes, requiring the use of the best published methods.
- Total nitrogen to total phosphorus ratios calculated from 1991 data indicated that nitrogen might be limiting to phytoplankton in Coville and Kukaklek lakes, as well as in Brooks and Naknek lakes where nitrogen imitation was first reported for lakes by Charles Goldman in the 1950s. The rest of the lakes measured had ratios indicating they might be phosphorus limited.
- Nutrient stimulation bioassays reconfirmed nitrogen limitation in Brooks Lake and demonstrated that Coville Lake was also nitrogen limited. Phosphorus limitation was indicated by experiments in Grosvenor and Kulik lakes (and possibly Nonvianuk Lake, where statistical significance was not attained).
- Additional, significant secondary stimulation by the other major nutrient was usually seen in these experiments, which was expected in such oligotrophic lakes. However, in Kulik Lake, where phosphorus was found to be the limiting nutrient, addition of nitrogen appeared to cause inhibition of phytoplankton growth, both when added alone or in combination with phosphorus.
- The relationships between phosphorus and phytoplankton biomass (as chlorophyll *a*) and both of these and resultant Secchi disk transparency among the Katmai lakes were very close to relationships developed for a large data set of U.S. lakes.
- The Katmai lakes (except the turbid Iliuk Arm of Naknek Lake) were clear, and algal and nonbiologic measurements (phosphorus

concentration and Secchi transparency) indexed these lakes as oligotrophic (Idavain Lake may index as mesotrophic, but too few measurements were taken to be sure).

- Battle Lake had a light penetration coefficient similar to that of Crater Lake, Oregon, one of the clearest lakes in the world. However, Battle Lake's Secchi depth was shallower than that of Crater Lake, probably due to small particulate matter that scattered light while not absorbing light. This scattering may be due to very small plankton (bacteria) or suspended inorganic material.
- Secchi transparency among the Katmai lakes was well explained by the phytoplankton biomass (as chlorophyll *a*). Therefore, to monitor eutrophication of these lakes, the Park needs only to generate a time series of seasonal average Secchi depths. Secchi measurements are much easier to take than light penetration, phytoplankton biomass, or total phosphorus measurements, which could also be taken if properly trained personnel are available.
- Zooplankton biomass was uniformly distributed throughout the entire water column in Coville and Grosvenor lakes at three of four sampling stations. Therefore, hauling from the bottom at synoptic stations probably did not bias results.
- Zooplankton biomass was lower in 1991 than in 1990 or 1992. This may have been due to the generally colder water temperatures of the lakes that summer.
- Among Katmai lakes, zooplankton biomass and phytoplankton biomass were significantly correlated. This was expected since zooplankton eat small phytoplankton (nannoplankton).

Streams

- Among measured streams, turbidity and suspended sediments were very highly significantly correlated. The Savonoski and Ukak rivers carry large amounts of suspended sediments that exert high turbidity.
- For the lakes where all major inlets were sampled, lake concentrations of major ions were in the middle of the range of inlet concentrations.
- Similar to the lakes, the inlet streams in general were similar in proportions of major cations, but the anions had widely variable proportions.
- Three inlets to Battle Lake had no titrable alkalinity, and another had only 2% alkalinity (of major anions). Chloride dominated most Battle Lake inlets except Iron Springs Creek, which was dominated by sulfate. Unusual inlets such as these may have an influence on the receiving lake, at least locally.
- Evidence of possibly toxic levels of aluminum for aquatic life were found in Iron Springs Creek, a tributary of Battle Lake, and Up-a-Tree and Headwater creeks, tributaries of Brooks Lake. Possibly acutely (lethally) toxic levels were measured in the Savonoski and Ukak rivers.
- Ions that indicate volcanic influence, boron and lithium, were measured in the Ukak and Savonoski rivers.
- Titanium, an indicator of igneous lithography, was measurable in American, Headwaters, and Margot creeks, and was highly elevated in the Savonoski and Ukak rivers.
- Phosphorus was high enough to be measured above high detection limits in the Savonoski and Ukak rivers, and in Up-a-Tree Creek, a Brooks Lake tributary, in 1991 during an historic high run of sockeye salmon.

- Methods with lower detection methods measured elevated total nitrogen and total phosphorus in both Up-a-Tree and Headwaters creeks in 1991 during the sockeye high.
- Algae dislodged from its attachment to stream bottom materials was strongly correlated with total phosphorus.
- The correlation of dislodged algae with suspended solids and turbidity among Katmai streams was probably explained by the fact that the majority of suspended material that exerts turbidity was probably scoured periphyton (attached algae), especially in clear streams.

Management Implications

Lakes

The lakes of this Park and Preserve are national treasures. They are extremely clear and pristine—where they are turbid, the sources are natural glacial rock flour and volcanic pumice and ash. Cultural eutrophication and resultant loss of water clarity of the large lakes will be improbable as long as they are protected by Park and Preserve status. Since the 11 lakes of the Naknek and Alagnak drainages are so large, the amount of human development that would eutrophy them would probably be equivalent to siting a large city in the watershed. However, careless waste disposal and land-clearing activities could certainly have local, temporary effects on transparency. Smaller lakes should be protected from receiving additional nitrogen and phosphorus by not allowing establishment of concessions that attract visitors to their watersheds. Such concessions are more appropriately sited near the large lakes and streams.

The four large lakes of the Alagnak drainage and the two highest altitude lakes, Murray and Hammersly, in the Naknek drainage are acid sensitive. The Park should be prepared to protect these lakes from activities

in their watersheds that would deposit acid precipitation (wet- or dryfall) in their watersheds (e.g., smelting, power generation, and urban automobile exhaust). Mining for metals, particularly those associated with reduced sulfur minerals, must expressly be prohibited in these watersheds. Battle Lake already receives acid-mine-type drainage, which may be natural. Allowing additional acidity to enter Battle Lake would possibly make the water even clearer and more transparent, but would probably harm the sockeye salmon runs to the inlets where they currently spawn.

Streams

The streams of the Katmai National Park and Preserve, particularly the smaller streams, should be protected from activities such as logging, mining, and so on that would have known harmful effects on them or on receiving waterbodies. Park employees and visitors should be cautioned not to use the waters of Iron Springs Creek (and probably all of the Battle Lake Inlets) or of the Ukak or Savonoski rivers as drinking water due to the possibility of high concentrations of toxic metals. Of course, staff and visitors should be informed of the dangers of drinking unfiltered (or unboiled) water from any source because of the danger of waterborne diseases.

Long-Term Monitoring Strategy

Lakes

- The large lakes that have not been bathymetrically mapped (Murray, Hammersly, and the four Alagnak lakes) should be at least roughly mapped before further studies.
- Stations should then be established, in each major basin of each lake to be monitored, by reference to bathymetric maps.

- At the first visit to each station, a GPS fix should be taken, and further sampling should be conducted by returning to that GPS location.
- Inlet stream chemical and physical studies should be conducted to establish secondary stations in areas that are locally affected by unusual imputs such as those found on Battle and Kulik lakes near metalliferous and thermal inlets.
- Secchi disk clarity is the primary characteristic that should be monitored in the lakes of Katmai National Park and Preserve. The appropriate sized disk and proper procedure (Carlson, 1995) should be used, and a viewscope should be utilized to remove the effects of surface disturbance, particularly that of wind.
- Monthly Secchi measurements should be made and a summer mean calculated. A steady upward trend in summer average Secchi depth (decreased water clarity) in a lake that continues for 5 or more years should signal possible eutrophication and the need for intensive limnological studies.
- Secondary to Secchi clarity, monthly chlorophyll-*a* measurements could also be made. They would provide a direct measurement of cultural eutrophication if it should occur. Samples should be depth-integrated to twice the Secchi depth, using Tygon tubing. At least 500 mL of water must be obtained for each sample to be filtered and the standard fluorometric method of analysis after acetone extraction used. The glass fiber filters used should be of the smallest effective pore size available (0.7 μm). Preferably, membrane sieve-type filters should be used with a pore size of 0.1 μm or 0.2 μm. These filters will capture the photosynthetic ultraplankton that are important in oligotrophic lakes.

Streams

- The largest streams in the Park and Preserve should be considered for long-term hydrographic studies in conjunction with the USGS. Alaska streams, in general, are not gaged at anywhere near the density of stations of the 48 contiguous states. Therefore, even major rivers, including the Alagnak and Naknek, are not gaged for flow. Flow data are needed for any stream where water quality characteristics are being measured. Without such data, concentrations of sediments, metals, and hydrocarbons (for a few examples) are difficult to interpret.
- Streams and other waterbodies that are used as drinking water by staff and visitors should be monitored, at least for comparison to (finished) drinking water standards. Additionally, if any carcinogens are found, comparison to ambient (raw) water quality standards should be made because they are often more restrictive. This level of caution is appropriate for National Parks and Preserves. These samples can be examined in the same process as is used for monitoring the public water supply wells in the Parks and Preserve, which is proscribed by Alaska law.

Suggestions for Further Research

Basic Science

- The large lakes in the Park and Preserve that have not been bathymetrically mapped should be at least roughly mapped before any further baseline research or monitoring is conducted.
- Several types of waterbodies in the Park and Preserve have not been adequately studied for their water quality and associated biota. They are the caldera lakes, other small lakes and ponds (particularly those associated with wetlands), streams, and individual geothermal springs.

- The influence of wetlands on nearby lakes and streams needs study, particularly as regards nutrient dynamics.
- The importance of aquatic bacteria among these lakes should be studied, as should the importance of periphyton. Each has the potential to be an important food source—the bacteria for zooplankton and the periphyton for benthic invertebrates. The periphyton is likely to be close in trophic importance to the phytoplankton, as has been found in Thingvallavatn, Iceland (Jonasson, 1992).
- The Characeae (vascular-looking algae) should be studied as substrate for particular invertebrates. They have been reported at great depths in Brooks Lake (to 15 to 20 m).
- The vascular aquatic plants of the wetlands and lakes should be studied for productivity and function.
- The unusual chemistry of the deep waters of Battle Lake should be studied to discover the extent of the deep, salty layer and its biological effects. The inlet streams should also be studied for their unusual chemistry and resulting biological effects, and for their local effects on the lake.
- If one of the 15 active volcanoes in this park vents material into the watershed of a waterbody (or several), a research project should immediately be started to establish the effects of such materials on water quality and the aquatic biota.

Phytoplankton

- The proportion of the phytoplankton that is nannoplankton and ultraplankton in the large lakes of the Park and Preserve should be investigated, since it is the size fraction that is zooplankton food.

- The phenomenon of deep (metalimnetic) peaks of algae should be investigated in these large lakes. Evidence of an algal peak at depth was seen in Nonvianuk Lake in 1991 while sampling for zooplankton.

Light Penetration and Scattering

- The relative influence of nannoplankton and inorganic sediments (including glacial flour) on light scattering and thus on Secchi clarity should be investigated in these lakes, particularly in Battle Lake, which has a relatively shallow Secchi depth compared to its very high light penetration depth.

Zooplankton

- The variation of the distribution of zooplankton in these lakes with area, depth, and time of day needs to be studied.
- The importance of zooplankton grazing on biomass measurements of phytoplankton algae among these lakes should be investigated.
- The inverse relation between barium and zooplankton standing crop among the 10 largest Katmai lakes should be investigated.

Benthic Invertebrates

- The facing spits along the Iliuk Arm of Naknek Lake should be investigated for hyporheic organisms, especially chironomids. We observed a spectacular hatch of chironomids there in early August 1992.

Fish

- The relative importance of the lakes of both drainages—the Naknek and the Alagnak—should be evaluated in the rearing of juvenile sockeye salmon. Some Battle Lake tributaries provide spawning habitat, but the

lake probably cannot rear young fish because of its extremely low productivity of algae and zooplankton and the possible toxicity of aluminum there.

Heavy Metals

- The biota of Iron Springs Creek and Lake, other inlets of Battle Lake and the lake itself, and of the Ukak and Savonoski rivers, should be studied in relation to the heavy metals in those systems.
- All surface waters that might be used by staff or visitors as drinking water should be examined for heavy metals, using methods with appropriately low detection limits for drinking water.

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Appendix A

Table A1. Lake ion balances, 1990, Katmai National Park and Preserve.

	Battle		Brooks		Coville	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	2.9	0.05	35.3	0.58	33.3	0.55
Cl	4.3	0.12	9.1	0.26	4.4	0.12
SO_4	15.0	0.31	0.0	0.00	0.0	0.00
Total anions:		0.48		0.83		0.67
Ca	3.83	0.19	8.11	0.41	7.16	0.36
Mg	0.75	0.062	2.09	0.17	1.62	0.13
K	<0.5	<0.01	<0.5	<0.01	<0.5	<0.01
Na	1.8	0.1	3.89	0.17	3.21	0.14
Total cations:		0.33		0.76		0.63
Ion sum:		0.81		1.59		1.30

	Grosvenor		Idavain		Kukaklek	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	30.5	0.50	25.6	0.42	8.8	0.14
Cl	4.9	0.14	8.3	0.23	6.3	0.18
SO_4	0.0	0.00	1.6	0.03	2.3	0.05
Total anions:		0.64		0.69		0.37
Ca	7.34	0.37	5.47	0.27	3.48	0.17
Mg	1.39	0.11	1.40	0.11	0.78	0.06
K	<0.5	<0.01	<0.5	<0.01	<0.5	<0.01
Na	2.88	0.13	2.87	0.12	2.23	0.10
Total cations:		0.61		0.51		0.33
Ion sum:		1.25		1.20		0.70

	Kulik		Murray		Naknek	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	7.7	0.13	10.7	0.18	37.6	0.62
Cl	8.1	0.23	8.8	0.25	12.8	0.36
SO_4	7.3	0.15	0.0	0.00	27.0	0.56
Total anions:		0.51		0.42		1.54
Ca	4.24	0.21	3.81	0.19	17.3	0.87
Mg	0.45	0.04	0.38	0.03	2.51	0.21
K	<0.5	<0.01	<0.5	<0.01	<0.5	<0.01
Na	1.4	0.06	1.4	0.06	6.83	0.30
Total cations:		0.31		0.28		1.37
Ion sum:		0.82		0.70		2.91

Table A1.Continued.

	Nonvianuk	
	mg/L	meq/L
HCO_3	12.2	0.20
Cl	8.9	0.25
SO_4	1.3	0.03
Total anions:		0.48
Ca	4.58	0.23
Mg	0.608	0.05
K	<0.5	<0.01
Na	1.7	0.07
Total cations:		0.35
Ion sum:		0.83

Table A2. Lake ion balances, 1991, Katmai National Park and Preserve.

	Battle		Brooks		Coville	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	2.4	0.04	34.9	0.57	28.5	0.47
Cl	4.6	0.13	9.8	0.28	3.7	0.10
SO_4	18	0.38	0	0.00	0	0.00
Total anions:		0.54		0.85		0.57
Ca	3.7	0.19	7.8	0.39	6.16	0.31
Mg	0.77	0.06	2.05	0.17	1.39	0.11
K	0.3	0.01	0.87	0.02	0.37	0.01
Na	1.67	0.1	3.61	0.16	2.81	0.12
Total cations:		0.33		0.74		0.55
Ion sum:		0.87		1.59		1.12

	Grosvenor		Hammersly		Kukaklek	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	29.0	0.48	11.8	0.19	9.4	0.15
Cl	10.5	0.30	9.6	0.27	8.9	0.25
SO_4	0	0.00	0	0.00	0	0.00
Total anions:		0.77		0.46		0.40
Ca	6.8	0.34	3.6	0.18	3.3	0.17
Mg	1.30	0.11	0.43	0.03	0.75	0.06
K	0.4	0.01	0.2	0.01	0.4	0.01
Na	2.71	0.12	1.30	0.06	2.03	0.09
Total cations:		0.57		0.28		0.33
Ion sum:		1.34		0.74		0.73

	Kulik		Murray		Naknek	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	8.4	0.14	9.5	0.16	37.8	0.62
Cl	2.9	0.08	2.6	0.07	14.7	0.41
SO_4	8	0.17	0	0.00	30	0.63
Total anions:		0.39		0.23		1.66
Ca	4.2	0.21	3.5	0.18	16.4	0.82
Mg	0.46	0.04	0.36	0.03	2.45	0.20
K	0.37	0.01	0.2	0.01	0.84	0.02
Na	1.27	0.06	1.23	0.05	6.45	0.28
Total cations:		0.31		0.26		1.32
Ion sum:		0.70		0.49		2.98

Table A2.Continued.

	Nonvianuk	
	mg/L	meq/L
HCO_3	12.0	0.20
Cl	3.0	0.08
SO_4	2	0.04
Total anions:		0.32
Ca	4.48	0.22
Mg	0.61	0.05
K	0.3	0.01
Na	1.60	0.07
Total cations:		0.35
Ion sum:		0.67

Table A3. Lake ion balances, 1992, Katmai National Park and Preserve.

	Battle		Brooks		Coville	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	2.0	0.03	34.9	0.57	29.3	0.48
Cl	1.0	0.03	2.4	0.07	0.9	0.03
SO_4	15	0.31	0	0.00	0	0.00
Total anions:		0.37		0.64		0.51
Ca	3.91	0.20	7.97	0.40	6.86	0.34
Mg	0.79	0.06	2.02	0.17	1.52	0.12
K	<1	<0.03	<1	<0.03	<1	<0.03
Na	1.7	0.1	3.7	0.16	3.0	0.13
Total cations:		0.36		0.73		0.59
Ion sum:		0.73		1.37		1.10

	Grosvenor		Hammersly		Kukaklek	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	29.9	0.49	11.1	0.18	8.4	0.14
Cl	0.9	0.03	0.4	0.01	1.5	0.04
SO_4	0	0.00	0	0.00	0	0.00
Total anions:		0.52		0.19		0.18
Ca	7.28	0.36	3.58	0.18	3.45	0.17
Mg	1.40	0.11	0.40	0.03	0.76	0.06
K	<1	<0.03	<1	<0.03	<1	<0.03
Na	2.9	0.13	1.3	0.06	2.2	0.10
Total cations:		0.60		0.27		0.33
Ion sum:		1.12		0.46		0.51

	Kulik		Murray		Naknek	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	7.7	0.13	10.4	0.17	35.4	0.58
Cl	0	0.00	0.5	0.01	4.5	0.13
SO_4	0	0.00	0	0.00	29	0.61
Total anions:		0.13		0.18		1.32
Ca	4.30	0.22	3.74	0.19	17.2	0.86
Mg	0.43	0.03	0.36	0.03	2.45	0.20
K	<1	<0.03	<1	<0.03	<1	<0.03
Na	1.3	0.06	1.3	0.06	6.56	0.29
Total cations:		0.31		0.28		1.35
Ion sum:		0.44		0.46		2.67

Table A3.Continued.

	Nonvianuk	
	mg/L	meq/L
HCO_3	11.5	0.19
Cl	0.7	0.02
SO_4	0	0.00
Total anions:		0.21
Ca	4.57	0.23
Mg	0.58	0.05
K	<1	<0.03
Na	1.6	0.07
Total cations:		0.35
Ion sum:		0.56

Table A4. Lake ion balances, 3-year averages, Katmai National Park and Preserve (1990-1992).

	Battle		Brooks		Coville	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	2.43	0.04	35.0	0.57	30.4	0.50
Cl	3.30	0.09	7.1	0.20	3.0	0.08
SO_4	16.0	0.33	0.0	0.00	0.0	0.00
Total anions:		0.46		0.77		0.58
Ca	3.81	0.19	7.96	0.40	6.7	0.33
Mg	0.77	0.06	2.05	0.17	1.5	0.12
K	<0.5	<0.01	<0.5	<0.01	<0.5	<0.01
Na	1.72	0.07	3.73	0.16	3.0	0.13
Total cations:		0.32		0.73		0.58
Ion sum:		0.78		1.50		1.16

	Grosvenor		Hammersly[a]		Idavain[b]	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	29.8	0.49	11.4	0.19	25.6	0.42
Cl	5.4	0.15	5.0	0.14	8.3	0.23
SO_4	0.0	0.00	0.0	0.00	1.6	0.03
Total anions:		0.64		0.33		0.69
Ca	7.1	0.35	3.6	0.18	5.47	0.27
Mg	1.36	0.11	0.4	0.03	1.40	0.11
K	<0.5	<0.01	<0.5	<0.01	<0.5	<0.01
Na	2.83	0.12	1.3	0.06	2.87	0.12
Total cations:		0.58		0.27		0.50
Ion sum:		1.22		0.60		1.19

[a] 1990 only

[b] 1991 and 1992 only

	Kukaklek		Kulik		Murray	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	8.87	0.14	7.93	0.13	10.20	0.17
Cl	5.60	0.16	3.70	0.10	3.80	0.11
SO_4	0.77	0.02	5.10	0.11	0.00	0.00
Total anions:		0.32		0.34		0.28
Ca	3.40	0.17	4.20	0.21	3.70	0.18
Mg	0.76	0.06	1.44	0.04	0.37	0.03
K	<0.5	<0.01	<0.5	<0.01	<0.5	<0.01
Na	2.15	0.09	1.32	0.06	1.31	0.06
Total cations:		0.32		0.31		0.27
Ion sum:		0.64		0.65		0.55

Table A4.Continued.

	Naknek		Nonvianuk	
	mg/L	meq/L	mg/L	meq/L
HCO_3	36.9	0.60	11.9	0.20
Cl	18.8	0.53	4.2	0.12
SO_4	28.7	0.59	1.1	0.02
Total anions:		1.72		0.34
Ca	17.0	0.85	4.50	0.22
Mg	2.47	0.20	0.60	0.05
K	<0.5	<0.01	<0.5	<0.01
Na	6.61	0.29	1.63	0.07
Total cations:		1.34		0.34
Ion sum:		3.06		0.68

Appendix B

Battle Lake	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	0.41	0.04	<0.03	0.15	± 0.56
AS :	<0.04	<0.04	<0.04		
B :	<0.03	<0.03	<0.03		
BA :	0.0038	0.0038	0.0035	0.0037	± 0.0004
BE :	<0.0006	<0.0006	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	3.89	3.78	3.81	3.83	± 0.14
CD :	<0.003	<0.003	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	0.036	<0.01	<0.01		
K :	<0.5	<0.5	<0.5		
LI :	<0.002	<0.002	<0.002		
MG :	0.766	0.745	0.751	0.754	± 0.027
MN :	0.023	0.022	0.023	0.023	± 0.001
MO :	<0.005	<0.005	<0.005		
NA :	1.8	1.7	1.8	1.8	± 0.1
NI :	<0.01	<0.01	<0.01		
P :	<0.2	<0.2	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08		
SI :	2.38	2.34	2.27	2.33	± 0.14
SN :	<0.05	<0.05	<0.05		
SR :	0.016	0.015	0.016	0.016	± 0.001
TI :	<0.003	<0.003	<0.003		
TL :	<0.08	<0.08	<0.08		
V :	<0.004	<0.004	<0.004		
ZN :	0.011	<0.003	<0.003		

Brooks Lake	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	<0.03	<0.03	<0.03		
AS :	<0.04	<0.04	<0.04		
B :	<0.03	<0.03	<0.03		
BA :	0.0019	0.0021	0.0022	0.0021	± 0.0004
BE :	<0.0006	<0.0006	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	8.02	8.45	7.87	8.11	± 0.75
CD :	<0.003	<0.003	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	0.02	0.092	0.035	0.049	± 0.095
K :	0.7	0.7	<0.5	0.47	± 1.0
LI :	<0.002	<0.002	<0.002		
MG :	2.07	2.17	2.04	2.09	± 0.17
MN :	<0.002	<0.002	<0.002		
MO :	<0.005	<0.005	<0.005		
NA :	3.80	4.06	3.82	3.89	± 0.36
NI :	<0.01	<0.01	<0.01		
P :	<0.2	<0.2	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08		
SI :	4.58	4.80	4.62	4.67	± 0.29
SN :	<0.05	<0.05	<0.05		
SR :	0.028	0.029	0.028	0.028	± 0.001
TI :	<0.003	<0.003	<0.003		
TL :	<0.08	<0.08	<0.08		
V :	<0.004	<0.004	<0.004		
ZN :	<0.003	<0.004	<0.003		

* 95% confidence intervals of the mean

Coville Lake	(mg/L)	(mg/L)	(mg/L)	Mean	± C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	<0.03	<0.03	<0.03		
AS :	<0.04	<0.04	<0.04		
B :	<0.03	<0.03	<0.03		
BA :	0.0016	0.001	0.001	0.0012	± 0.0009
BE :	<0.0006	<0.0006	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	7.45	7.02	7.0	7.16	± 0.64
CD :	<0.003	<0.003	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	0.23	0.63	0.07	0.31	± 0.72
K :	<0.5	<0.5	<0.5		
LI :	<0.002	<0.002	<0.002		
MG :	1.68	1.59	1.59	1.62	± 0.13
MN :	0.0077	0.0084	0.007	0.0077	± 0.0018
MO :	<0.005	<0.005	<0.005		
NA :	3.29	3.16	3.17	3.21	± 0.18
NI :	<0.01	<0.01	<0.01		
P :	<0.2	<0.2	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08		
SI :	4.35	4.17	4.23	4.25	± 0.23
SN :	<0.05	<0.05	<0.05		
SR :	0.027	0.026	0.026	0.026	± 0.002
TI :	<0.003	<0.003	<0.003		
TL :	<0.08	<0.08	<0.08		
V :	<0.004	<0.004	<0.004		
ZN :	<0.003	<0.003	<0.003		

Grosvenor Lake	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	<0.03	<0.03	<0.03		
AS :	<0.04	<0.04	<0.04		
B :	<0.03	<0.03	<0.03		
BA :	0.0018	0.0023	0.0016	0.0019	± 0.0009
BE :	<0.0006	<0.0006	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	7.68	7.29	7.05	7.34	± 0.79
CD :	<0.003	<0.003	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	0.093	0.13	0.01	0.08	± 0.15
K :	<0.5	0.7	<0.5		
LI :	<0.002	<0.002	<0.002		
MG :	1.45	1.38	1.33	1.39	± 0.15
MN :	<0.002	<0.002	<0.002		
MO :	<0.005	<0.005	<0.005		
NA :	3.04	2.9	2.7	2.88	± 0.43
NI :	<0.01	<0.01	<0.01		
P :	<0.2	<0.2	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08		
SI :	3.72	3.61	3.36	3.56	± 0.46
SN :	<0.05	<0.05	<0.05		
SR :	0.025	0.025	0.023	0.024	± 0.003
TI :	<0.003	<0.003	<0.003		
TL :	<0.08	<0.08	<0.08		
V :	<0.004	<0.004	<0.004		
ZN :	<0.003	<0.003	<0.003		

Idavain Lake	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	<0.03	<0.03	<0.03		
AS :	<0.04	<0.04	<0.04		
B :	<0.03	<0.03	<0.03		
BA :	0.0016	0.0017	0.001	0.0014	± 0.0009
BE :	<0.0006	<0.0006	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	5.39	5.43	5.60	5.47	± 0.28
CD :	<0.003	<0.003	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	0.032	0.03	0.035	0.032	± 0.006
K :	<0.5	<0.5	<0.5		
LI :	<0.002	<0.002	<0.002		
MG :	1.38	1.39	1.42	1.40	± 0.05
MN :	0.0092	0.009	0.0086	0.0089	± 0.0008
MO :	<0.005	<0.005	<0.005		
NA :	2.91	2.86	2.84	2.87	± 0.09
NI :	<0.01	<0.01	<0.01		
P :	<0.2	<0.2	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08		
SI :	3.36	3.40	3.33	3.36	± 0.09
SN :	<0.05	<0.05	<0.05		
SR :	0.024	0.024	0.024	0.024	± 0.000
TI :	<0.003	<0.003	<0.003		
TL :	<0.08	<0.08	<0.08		
V :	<0.004	<0.004	<0.004		
ZN :	<0.003	<0.003	<0.003		

Kukaklek Lake	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	<0.03	0.03	<0.03		
AS :	<0.04	<0.04	<0.04		
B :	<0.03	<0.03	<0.03		
BA :	0.001	0.001	0.0009	0.0010	± 0.0001
BE :	<0.0006	<0.0006	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	3.52	3.57	3.36	3.48	± 0.27
CD :	<0.003	<0.003	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	<0.01	0.055	<0.01		
K :	<0.5	<0.5	<0.5		
LI :	<0.002	<0.002	<0.002		
MG :	0.786	0.798	0.756	0.780	± 0.054
MN :	<0.002	0.003	<0.002		
MO :	<0.005	<0.005	<0.005		
NA :	2.23	2.25	2.20	2.23	± 0.06
NI :	<0.01	<0.01	<0.01		
P :	<0.2	<0.2	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08		
SI :	1.39	1.41	1.32	1.37	± 0.12
SN :	<0.05	<0.05	<0.05		
SR :	0.013	0.013	0.013	0.013	± 0.000
TI :	<0.003	<0.003	<0.003		
TL :	<0.08	<0.08	<0.08		
V :	<0.004	<0.004	<0.004		
ZN :	<0.003	0.006	<0.003		

* 95% confidence intervals of the mean

Kulik Lake	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*	Murray Lake	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01			AG :	<0.01	<0.01	<0.01		
AL :	<0.03	<0.03	<0.03			AL :	0.42	0.04	<0.03	0.15	± 0.58
AS :	<0.04	<0.04	<0.04			AS :	<0.04	<0.05	<0.05		
B :	<0.03	<0.03	<0.03			B :	<0.03	<0.03	<0.03		
BA :	0.0032	0.003	0.0031	0.0031	± 0.0002	BA :	0.0027	0.0031	0.0032	0.0030	± 0.0008
BE :	<0.0006	<0.0006	<0.0006			BE :	<0.0006	<0.0005	<0.0005		
BI :	<0.04	<0.04	<0.04			BI :	<0.04	<0.04	<0.04		
CA :	4.19	4.23	4.30	4.24	± 0.14	CA :	3.80	3.76	3.87	3.81	± 0.14
CD :	<0.003	<0.003	<0.003			CD :	<0.003	<0.004	<0.004		
CO :	<0.01	<0.01	<0.01			CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01			CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003			CU :	<0.003	<0.003	<0.003		
FE :	<0.01	0.02	0.061	0.027	± 0.077	FE :	0.056	0.089	0.077	0.074	± 0.042
K :	<0.5	<0.5	<0.5			K :	<0.5	<0.4	<0.4		
LI :	<0.002	<0.002	<0.002			LI :	<0.002	<0.002	<0.002		
MG :	0.440	0.447	0.452	0.446	± 0.015	MG :	0.382	0.383	0.386	0.384	± 0.005
MN :	<0.002	<0.002	<0.002			MN :	<0.002	<0.002	<0.002		
MO :	<0.005	<0.005	<0.005			MO :	<0.005	<0.006	<0.006		
NA :	1.3	1.4	1.4	1.4	± 0.1	NA :	1.5	1.3	1.3	1.4	± 0.3
NI :	<0.01	<0.01	<0.01			NI :	<0.01	<0.02	<0.02		
P :	<0.2	<0.2	<0.2			P :	<0.2	<0.1	<0.1		
PB :	<0.04	<0.04	<0.04			PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04			SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08			SE :	<0.08	<0.07	<0.07		
SI :	2.22	2.29	2.36	2.29	± 0.18	SI :	2.62	2.45	2.52	2.53	± 0.21
SN :	<0.05	<0.05	<0.05			SN :	<0.05	<0.04	<0.04		
SR :	0.016	0.016	0.016	0.016	± 0.000	SR :	0.012	0.012	0.012	0.012	± 0.000
TI :	<0.003	<0.003	<0.003			TI :	<0.003	<0.002	<0.002		
TL :	<0.08	<0.08	<0.08			TL :	<0.08	<0.06	<0.06		
V :	<0.004	<0.004	<0.004			V :	<0.004	<0.003	<0.003		
ZN :	<0.003	<0.003	<0.003			ZN :	0.0097	0.029	0.04	0.026	± 0.038

* 95% confidence intervals of the mean

Naknek	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	0.26	0.05	<0.03	0.10	± 0.34
AS :	<0.04	<0.05	<0.04		
B :	0.04	0.05	0.04	0.04	± 0.01
BA :	0.0038	0.0042	0.0041	0.0040	± 0.0005
BE :	<0.0006	<0.0005	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	17.5	17.3	17.0	17.3	± 0.6
CD :	<0.003	<0.004	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	0.14	0.02	0.01	0.06	± 0.18
K :	0.5	<0.4	<0.5		
LI :	0.012	0.011	0.012	0.012	± 0.001
MG :	2.53	2.51	2.48	2.51	± 0.06
MN :	<0.002	<0.002	<0.002		
MO :	<0.005	<0.006	<0.005		
NA :	6.81	6.68	6.99	6.83	± 0.39
NI :	<0.01	<0.02	<0.01		
P :	<0.2	<0.1	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.07	<0.08		
SI :	3.89	3.73	3.88	3.83	± 0.22
SN :	<0.05	<0.04	<0.05		
SR :	0.048	0.048	0.049	0.048	± 0.001
TI :	<0.003	<0.002	<0.003		
TL :	<0.08	<0.06	<0.08		
V :	<0.004	<0.003	<0.004		
ZN :	0.007	0.032	<0.003	0.013	± 0.042

Nonvlanuk	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	<0.01	<0.01	<0.01		
AL :	<0.03	<0.03	<0.03		
AS :	<0.04	<0.04	<0.04		
B :	<0.03	<0.03	<0.03		
BA :	0.0024	0.0025	0.0026	0.0025	± 0.0002
BE :	<0.0006	<0.0006	<0.0006		
BI :	<0.04	<0.04	<0.04		
CA :	4.63	4.40	4.72	4.58	± 0.41
CD :	<0.003	<0.003	<0.003		
CO :	<0.01	<0.01	<0.01		
CR :	<0.01	<0.01	<0.01		
CU :	<0.003	<0.003	<0.003		
FE :	0.059	<0.01	0.076		
K :	<0.5	<0.6	<0.5		
LI :	<0.002	<0.002	<0.002		
MG :	0.612	0.582	0.63	0.608	± 0.061
MN :	<0.002	<0.002	<0.002		
MO :	<0.005	<0.005	<0.005		
NA :	1.7	1.6	1.7	1.7	± 0.1
NI :	<0.01	<0.01	<0.01		
P :	<0.2	<0.2	<0.2		
PB :	<0.04	<0.04	<0.04		
SB :	<0.04	<0.04	<0.04		
SE :	<0.08	<0.08	<0.08		
SI :	1.69	1.61	1.96	1.75	± 0.46
SN :	<0.05	<0.05	<0.05		
SR :	0.016	0.016	0.016	0.016	± 0.000
TI :	<0.003	<0.003	0.006		
TL :	<0.08	<0.08	<0.08		
V :	<0.004	<0.004	<0.004		
ZN :	<0.003	<0.003	<0.003		

* 95% confidence intervals of the mean

Battle Lake 1m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.04	0.06	0.06	0.05	± 0.03
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0034	0.0034	0.0035	0.0034	± 0.0001
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.6	3.6	3.7	3.6	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.009	0.010	0.017	0.012	± 0.011
K :	< 0.2	0.4	0.3	0.2	± 0.5
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.732	0.739	0.742	0.738	± 0.013
MN :	0.022	0.023	0.023	0.023	± 0.001
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.60	1.60	1.60	1.60	± 0.00
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.12	2.13	2.15	2.13	± 0.04
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.014	0.014	0.015	0.014	± 0.001
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.0082	< 0.002	< 0.002		

Battle Lake 2m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.030	0.030	0.061	0.040	± 0.045
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0034	0.0036	0.0034	0.0035	± 0.0003
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.6	3.7	3.7	3.7	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.010	0.010	0.018	0.013	± 0.012
K :	< 0.2	0.58	0.3	0.3	± 0.7
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.728	0.752	0.751	0.744	± 0.034
MN :	0.022	0.024	0.024	0.023	± 0.003
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.60	1.70	1.70	1.67	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.10	2.16	2.17	2.14	± 0.09
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.015	0.015	0.015	± 0.000
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

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Battle Lake 3m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.03	0.03	0.06	0.04	± 0.04
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0035	0.0036	0.0034	0.004	± 0.0002
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.7	3.7	3.6	3.7	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	0.003		
FE :	0.034	0.015	0.023	0.024	± 0.024
K :	0.2	0.3	0.3	0.3	± 0.1
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.741	0.744	0.741	0.742	± 0.004
MN :	0.024	0.024	0.024	0.024	± 0.000
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.60	1.70	1.60	1.63	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.14	2.16	2.13	2.14	± 0.04
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.015	0.015	0.015	± 0.000
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	0.005		

Battle Lake 4m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.04	0.04	0.03	0.04	± 0.01
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0037	0.0034	0.0034	0.0035	± 0.0004
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.7	3.7	3.6	3.7	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.016	0.02	0.015	0.017	± 0.007
K :	0.3	0.3	< 0.2	0.2	± 0.4
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.745	0.751	0.740	0.745	± 0.014
MN :	0.025	0.025	0.024	0.025	± 0.001
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.70	1.70	1.70	1.70	± 0.00
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.14	2.16	2.14	2.15	± 0.03
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.015	0.015	0.015	± 0.000
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

* 95% confidence intervals of the mean

Battle Lake 5m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.03	0.04	0.10	0.06	± 0.09
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0033	0.0036	0.0036	0.004	± 0.0004
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.004		
CA :	3.60	3.70	3.54	3.61	± 0.20
CD :	< 0.002	< 0.002	< 0.003		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.016	0.015	0.030	0.020	± 0.021
K :	< 0.2	0.4	< 0.3	0.2	± 0.5
W :	< 0.01	< 0.01	< 0.02		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.733	0.743	0.705	0.727	± 0.049
MN :	0.023	0.025	0.021	0.023	± 0.005
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.70	1.70	1.60	1.67	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.05		
SI :	2.11	2.19	2.33	2.21	± 0.28
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.015	0.015	0.015	± 0.000
TI :	< 0.002	< 0.002	0.003		
TL :	< 0.04	< 0.04	< 0.08		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	0.005	< 0.002		

Battle Lake 10m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.040	0.068	0.071	0.060	± 0.043
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0035	0.0035	0.0037	0.0036	± 0.0003
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.7	3.7	3.7	3.7	± 0.0
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	0.004	< 0.002	< 0.002		
FE :	0.018	0.017	0.010	0.015	± 0.011
K :	< 0.2	0.64	0.4	0.3	± 0.8
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.743	0.746	0.749	0.746	± 0.008
MN :	0.024	0.024	0.024	0.024	± 0.000
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.70	1.60	1.60	1.63	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.14	2.16	2.16	2.15	± 0.03
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.015	0.015	0.015	± 0.000
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.004	0.002	< 0.002	0.002	± 0.005

Battle Lake 20m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.060	0.064	0.067	0.064	± 0.009
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0037	0.0033	0.0034	0.0035	± 0.0005
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.7	3.52	3.5	3.6	± 0.3
CD :	< 0.002	< 0.003	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.019	0.020	0.016	0.018	± 0.005
K :	< 0.2	0.4	< 0.2		
W :	< 0.01	< 0.02	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.758	0.698	0.717	0.724	± 0.077
MN :	0.025	0.021	0.024	0.023	± 0.005
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.70	1.60	1.60	1.63	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.05	< 0.04		
SI :	2.18	2.07	2.06	2.10	± 0.17
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.016	0.015	0.014	0.015	± 0.003
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.08	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.002	< 0.003	< 0.002		

Battle Lake 30m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.04	0.03	0.05	0.04	± 0.03
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0035	0.0034	0.0035	0.0035	± 0.0001
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.6	3.5	3.5	3.5	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	0.003	< 0.002	< 0.002		
FE :	0.024	0.019	0.021	0.021	± 0.006
K :	0.3	< 0.2	0.3	0.2	± 0.4
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.725	0.705	0.699	0.710	± 0.034
MN :	0.025	0.025	0.023	0.024	± 0.003
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.70	1.60	1.60	1.63	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.15	2.08	2.06	2.10	± 0.12
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.015	0.014	0.015	± 0.001
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.006	< 0.002	< 0.002		

* 95% confidence intervals of the mean

Battle Lake 40m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.03	0.02	0.03	0.03	± 0.01
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0034	0.0034	0.0036	0.0035	± 0.0003
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.7	3.6	3.9	3.7	± 0.4
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	0.004		
FE :	0.010	0.010	0.022	0.014	± 0.017
K :	0.2	< 0.2	0.3	0.17	± 0.38
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.740	0.715	0.762	0.739	± 0.059
MN :	0.026	0.025	0.028	0.026	± 0.004
MO :	< 0.005	< 0.005	0.006		
NA :	1.70	1.60	1.70	1.67	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.15	2.10	2.21	2.15	± 0.14
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.014	0.015	0.015	± 0.001
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.002	0.002	0.005	0.003	± 0.004

Battle Lake 50m	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0037	0.0035	0.0027	0.0033	± 0.0013
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.8	3.9	2.9	3.5	± 1.4
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	0.004	< 0.002	< 0.002		
FE :	0.009	0.015	0.010	0.011	± 0.008
K :	0.2	0.2	< 0.2	0.13	± 0.29
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.764	0.767	0.585	0.705	± 0.261
MN :	0.029	0.029	0.021	0.026	± 0.012
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.70	1.70	1.30	1.57	± 0.58
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.18	2.20	1.69	2.02	± 0.72
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.016	0.012	0.014	± 0.005
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.003	< 0.002	0.003	0.002	± 0.004

Katmai Lakes - Metals - 1991

Battle	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.093	0.110	0.110	0.104 ± 0.025	
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0037	0.0037	0.0036	0.0037 ± 0.0001	
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.7	3.7	3.7	3.7 ± 0.0	
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.02	0.02	0.02	0.02 ± 0.00	
K :	0.2	0.3	0.3	0.3 ± 0.1	
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.769	0.764	0.771	0.768 ± 0.009	
MN :	0.025	0.025	0.025	0.025 ± 0.000	
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.70	1.60	1.70	1.67 ± 0.14	
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.21	2.18	2.26	2.22 ± 0.10	
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.016	0.015	0.015	0.015 ± 0.001	
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	0.002	< 0.002		

Brooks	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0023	0.0021	0.0022	0.0022 ± 0.0003	
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	8.0	7.6	7.8	7.8 ± 0.5	
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.018	0.017	0.016	0.017 ± 0.002	
K :	0.92	0.97	0.73	0.87 ± 0.32	
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	2.10	1.99	2.05	2.05 ± 0.14	
MN :	< 0.002	< 0.002	< 0.002		
MO :	< 0.005	< 0.005	< 0.005		
NA :	3.73	3.47	3.64	3.61 ± 0.33	
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	4.19	3.94	4.06	4.06 ± 0.31	
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.028	0.026	0.027	0.027 ± 0.002	
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

* 95% confidence intervals of the mean

Katmai Lakes - Metals - 1991

Coville	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0016	0.0017	0.0017	0.0017	± 0.0001
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	6.20	6.20	6.07	6.16	± 0.19
CD :	< 0.002	< 0.002	< 0.003		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	0.003	< 0.002		
FE :	0.10	0.11	0.10	0.10	± 0.01
K :	0.20	0.51	0.40	0.37	± 0.39
W :	< 0.01	< 0.01	< 0.02		
LI :	< 0.002	< 0.002	< 0.002		
MG :	1.40	1.40	1.37	1.39	± 0.04
MN :	0.004	0.004	0.005	0.004	± 0.001
MO :	< 0.005	< 0.005	< 0.005		
NA :	2.83	2.80	2.80	2.81	± 0.04
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.05		
SI :	3.83	3.82	3.88	3.84	± 0.08
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.024	0.023	0.023	0.023	± 0.001
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.08		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.002	< 0.002	0.0096	0.004	± 0.130

Grosvenor	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0018	0.0017	0.0018	0.0018	± 0.0001
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	6.8	6.7	6.8	6.8	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.038	0.041	0.040	0.040	± 0.004
K :	0.4	0.4	0.4	0.4	± 0.0
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	1.30	1.30	1.30	1.30	± 0.00
MN :	0.003	0.003	0.003	0.003	± 0.000
MO :	< 0.005	< 0.005	< 0.005		
NA :	2.72	2.69	2.73	2.71	± 0.05
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	3.33	3.29	3.33	3.32	± 0.06
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.023	0.023	0.023	0.023	± 0.000
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	0.0075		

Hammersly	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0028	0.0028	0.0029	0.0028	± 0.0001
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.6	3.5	3.6	3.6	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.01	0.01	0.01	0.01	± 0.00
K :	0.3	< 0.2	0.3	0.2	± 0.4
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.429	0.425	0.423	0.426	± 0.008
MN :	< 0.002	< 0.002	< 0.002		
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.30	1.30	1.30	1.30	± 0.00
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.32	2.26	2.27	2.28	± 0.08
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.012	0.012	0.012	0.012	± 0.000
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

Kulik	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0032	0.0031	0.0034	0.0032	± 0.0004
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	4.2	4.1	4.3	4.2	± 0.2
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.020	0.021	0.020	0.020	± 0.001
K :	0.300	0.300	0.520	0.373	± 0.318
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.456	0.447	0.463	0.455	± 0.020
MN :	0.002	0.002	0.002	0.002	± 0.000
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.30	1.20	1.30	1.27	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.16	2.12	2.2	2.16	± 0.10
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.015	0.014	0.015	0.015	± 0.001
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	0.002	< 0.002	< 0.002		

* 95% confidence intervals of the mean

Appendix B2

Katmai Lakes - Metals - 1991

Kukaklek	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.001	0.001	0.001	0.001	± 0.000
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.3	3.2	3.3	3.3	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	0.002		
FE :	0.01	0.01	0.01	0.01	± 0.00
K :	0.4	0.4	0.3	0.4	± 0.1
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.769	0.740	0.754	0.754	± 0.036
MN :	0.002	0.003	0.002	0.002	± 0.001
MO :	< 0.005	< 0.005	< 0.005		
NA :	2.06	2.00	2.04	2.03	± 0.08
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	1.32	1.27	1.29	1.29	± 0.06
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.012	0.012	0.012	0.012	± 0.000
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

Murray	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	0.03	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.003	0.003	0.003	0.003	± 0.000
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	3.6	3.5	3.5	3.5	± 0.1
CD :	< 0.002	< 0.002	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.047	0.051	0.043	0.047	± 0.010
K :	0.3	0.2	0.2	0.2	± 0.1
W :	< 0.01	< 0.01	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.371	0.361	0.361	0.364	± 0.014
MN :	0.002	0.002	0.003	0.002	± 0.001
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.30	1.20	1.20	1.23	± 0.14
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.04	< 0.04		
SI :	2.38	2.37	2.30	2.35	± 0.11
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.012	0.011	0.011	0.011	± 0.001
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.04	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

* 95% confidence intervals of the mean

Katmai Lakes - Metals - 1991

Naknek	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	0.05	0.05	0.04	0.05 ± 0.01	
AS :	< 0.04	< 0.04	< 0.04		
B :	0.05	0.04	0.05	0.05 ± 0.01	
BA :	0.0042	0.0043	0.0040	0.0042 ± 0.0004	
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	17.0	16.3	16.0	16.4 ± 1.3	
CD :	< 0.002	< 0.003	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.043	0.069	0.045	0.052 ± 0.036	
K :	1.20	0.80	0.52	0.84 ± 0.85	
W :	< 0.01	< 0.02	< 0.01		
LI :	0.010	0.011	0.011	0.011 ± 0.001	
MG :	2.53	2.38	2.44	2.45 ± 0.19	
MN :	0.003	< 0.002	< 0.002		
MO :	< 0.005	< 0.005	< 0.005		
NA :	6.58	6.38	6.39	6.45 ± 0.28	
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.05	< 0.04		
SI :	3.67	3.53	3.50	3.57 ± 0.23	
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.047	0.046	0.046	0.046 ± 0.001	
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.08	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

Nonvianuk	(mg/L)	(mg/L)	(mg/L)	Mean	C.I.*
AG :	< 0.01	< 0.01	< 0.01		
AL :	< 0.02	< 0.02	< 0.02		
AS :	< 0.04	< 0.04	< 0.04		
B :	< 0.02	< 0.02	< 0.02		
BA :	0.0029	0.0029	0.0027	0.0028 ± 0.0003	
BE :	< 0.0005	< 0.0005	< 0.0005		
BI :	< 0.04	< 0.04	< 0.04		
CA :	4.60	4.43	4.40	4.48 ± 0.27	
CD :	< 0.002	< 0.003	< 0.002		
CO :	< 0.01	< 0.01	< 0.01		
CR :	< 0.01	< 0.01	< 0.01		
CU :	< 0.002	< 0.002	< 0.002		
FE :	0.010	< 0.005	0.008	0.006 ± 0.013	
K :	0.46	< 0.30	0.3	0.3 ± 0.6	
W :	< 0.01	< 0.02	< 0.01		
LI :	< 0.002	< 0.002	< 0.002		
MG :	0.626	0.588	0.608	0.607 ± 0.048	
MN :	< 0.002	< 0.002	< 0.002		
MO :	< 0.005	< 0.005	< 0.005		
NA :	1.60	1.60	1.60	1.60 ± 0.00	
NI :	< 0.01	< 0.01	< 0.01		
P :	< 0.09	< 0.09	< 0.09		
PB :	< 0.04	< 0.04	< 0.04		
SB :	< 0.04	< 0.04	< 0.04		
SE :	< 0.04	< 0.05	< 0.04		
SI :	1.60	1.52	1.54	1.55 ± 0.10	
SN :	< 0.04	< 0.04	< 0.04		
SR :	0.016	0.016	0.016	0.016 ± 0.000	
TI :	< 0.002	< 0.002	< 0.002		
TL :	< 0.04	< 0.08	< 0.04		
V :	< 0.003	< 0.003	< 0.003		
ZN :	< 0.002	< 0.002	< 0.002		

* 95% confidence intervals of the mean

Battle	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	0.18	0.16	0.19	0.18 ± 0.03
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	0.0042	0.0025	0.0029	0.0032 ± 0.0018
BE	<0.0002	<0.0002	<0.0002	
BI	<0.04	<0.04	<0.04	
CA	3.99	3.87	3.86	3.91 ± 0.15
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	0.036	0.022	0.022	0.027 ± 0.016
K	<1.	<1.	<1.	
W	<0.03	<0.03	<0.03	
LI	<0.004	<0.004	<0.004	
MG	0.806	0.784	0.785	0.792 ± 0.025
MN	0.025	0.025	0.025	0.025 ± 0
MO	<0.01	<0.01	<0.01	
NA	1.7	1.6	1.7	1.7 ± 0.1
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.06	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	2.3	2.2	2.2	2.2 ± 0.1
SN	<0.06	<0.06	<0.06	
SR	0.016	0.015	0.015	0.015 ± 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	<0.005	

Brooks	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	<0.05	0.1	<0.05	
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	0.02	
BA	0.0019	0.0021	0.0025	0.0022 ± 0.0006
BE	<0.0002	<0.0002	<0.0002	
BI	<0.04	<0.04	<0.04	
CA	7.97	8.04	7.91	7.97 ± 0.13
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	0.019	0.023	0.02	0.021 ± 0.004
K	<1.	<1.	<1.	
W	0.03	<0.03	<0.03	
LI	<0.004	<0.004	<0.004	
MG	2.02	2.05	2.000	2.023 ± 0.051
MN	0.001	<0.001	<0.001	
MO	<0.01	<0.01	<0.01	
NA	3.6	3.7	3.7	3.7 ± 0.1
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.06	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	3.8	3.7	3.7	3.7 ± 0.1
SN	<0.06	<0.06	<0.06	
SR	0.027	0.027	0.027	0.027 ± 0
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	<0.005	

Coville	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	0.11	0.08	<0.05	0.06 ± 0.12
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	0.002	0.001	0.001	0.001 ± 0.001
BE	<0.0002	<0.0002	<0.0002	
BI	<0.04	<0.04	<0.04	
CA	6.89	6.87	6.81	6.86 ± 0.08
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	0.099	0.081	0.057	0.079 ± 0.043
K	<1.	<1.	<1.	
W	<0.03	0.04	<0.03	
LI	<0.004	<0.004	<0.004	
MG	1.53	1.52	1.50	1.52 ± 0.03
MN	0.0058	0.0049	0.0056	0.0054 ± 0.0010
MO	<0.01	<0.01	<0.01	
NA	3.0	3.0	3.0	3.0 ± 0
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.07	0.09	0.07	0.05 ± 0.10
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	3.4	3.4	3.7	3.5 ± 0.4
SN	<0.06	<0.06	<0.06	
SR	0.025	0.025	0.024	0.025 ± 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	0.005	

Grosvenor	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	<0.05	<0.05	<0.05	
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	0.0015	0.0017	0.001	0.0014 ± 0.0007
BE	<0.0002	<0.0002	0.0002	
BI	<0.04	<0.04	<0.04	
CA	7.26	7.30	7.28	7.28 ± 0.04
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	0.024	0.026	0.020	0.023 ± 0.006
K	<1.	<1.	<1.	
W	<0.03	0.03	<0.03	
LI	<0.004	<0.004	<0.004	
MG	1.40	1.41	1.40	1.40 ± 0.01
MN	0.002	0.002	0.002	0.002 ± 0
MO	<0.01	<0.01	<0.01	
NA	2.9	2.9	2.9	2.9 ± 0
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.06	0.08	0.07	0.05 ± 0.09
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	3.3	3.4	3.3	3.3 ± 0.1
SN	<0.06	<0.06	<0.06	
SR	0.024	0.025	0.024	0.024 ± 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	0.006	0.006	0.009	0.007 ± 0.004

Hammersly	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	<0.05	<0.05	<0.05	
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	0.0023	0.0023	0.0022	0.0023 ± 0.0001
BE	<0.0002	<0.0002	<0.0002	
BI	<0.04	0.04	<0.04	
CA	3.57	3.57	3.61	3.58 ± 0.05
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	<0.006	<0.006	<0.006	
K	<1.	<1.	<1.	
W	<0.03	<0.03	0.04	
LI	<0.004	<0.004	<0.004	
MG	0.400	0.398	0.404	0.401 ± 0.006
MN	<0.001	0.001	<0.001	
MO	<0.01	<0.01	<0.01	
NA	1.3	1.3	1.3	1.3 ± 0
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.06	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	2.1	2.2	2.1	2.1 ± 0.1
SN	<0.06	<0.06	<0.06	
SR	0.011	0.012	0.012	0.012 ± 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	<0.005	

Kukaklek	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	<0.05	<0.05	<0.05	
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	<0.0004	<0.0004	0.0007	
BE	<0.0002	<0.0002	<0.0002	
BI	<0.04	0.04	<0.04	
CA	3.56	3.43	3.37	3.45 ± 0.20
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	<0.006	<0.006	0.006	
K	<1.	<1.	<1.	
W	0.07	<0.03	<0.03	
LI	<0.004	<0.004	<0.004	
MG	0.773	0.757	0.743	0.758 ± 0.030
MN	0.001	0.001	<0.001	0.001 ± 0.001
MO	<0.01	<0.01	<0.01	
NA	2.2	2.2	2.1	2.2 ± 0.1
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	0.07	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	1.4	1.2	1.3	1.3 ± 0.2
SN	<0.06	<0.06	<0.06	
SR	0.013	0.012	0.012	0.012 ± 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	<0.005	

Kulik	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	<0.05	<0.05	<0.05	
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	0.0025	0.0023	0.0028	0.0025 ± 0.0005
BE	<0.0002	<0.0002	<0.0002	
BI	<0.04	<0.04	<0.04	
CA	4.33	4.20	4.37	4.30 ± 0.18
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	<0.006	<0.006	<0.006	
K	<1.	<1.	<1.	
W	<0.03	<0.03	<0.03	
LI	<0.004	<0.004	<0.004	
MG	0.432	0.424	0.443	0.433 ± 0.019
MN	0.002	<0.001	0.002	0.001 ± 0.002
MO	<0.01	<0.01	<0.01	
NA	1.3	1.2	1.3	1.3 ± 0.1
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.06	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	2.0	2.0	2.1	2.0 ± 0.1
SN	<0.06	<0.06	<0.06	
SR	0.015	0.014	0.015	0.015 ± 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	<0.005	

Murray	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	<0.05	<0.05	<0.05	
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	0.0023	0.0022	0.0021	0.0022 ± 0.0002
BE	<0.0002	<0.0002	<0.0002	
BI	<0.04	<0.04	<0.05	
CA	3.75	3.71	3.75	3.74 ± 0.05
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	0.006	<0.006	0.02	0.009 ± 0.021
K	<1.	<1.	<1.	
W	<0.03	<0.03	<0.03	
LI	<0.004	<0.004	<0.004	
MG	0.358	0.356	0.356	0.357 ± 0.002
MN	0.002	0.0031	0.002	0.002 ± 0.001
MO	<0.01	<0.01	<0.01	
NA	1.3	1.3	1.3	1.3 ± 0
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.06	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	2.2	2.2	2.2	2.2 ± 0
SN	<0.06	<0.06	<0.06	
SR	0.012	0.011	0.012	0.012 ± 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	<0.005	

Naknek	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	0.1	0.07	<0.05	0.06 ± 0.10
AS	<0.1	<0.1	<0.1	
B	0.05	0.05	0.06	0.05 ± 0.01
BA	0.0046	0.0042	0.0039	0.0042 ± 0.0007
BE	0.0002	<0.0002	<0.0002	
BI	<0.04	<0.04	<0.04	
CA	17.2	17.2	17.2	17.2 ± 0
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	0.008	<0.007	<0.007	
FE	0.043	0.024	0.025	0.031 ± 0.022
K	<1.	<1.	<1.	
W	<0.03	<0.03	<0.03	
LI	0.008	0.004	0.007	0.006 ± 0.004
MG	2.45	2.46	2.45	2.45 ± 0.01
MN	0.002	<0.001	<0.001	
MO	<0.01	<0.01	<0.01	
NA	6.57	6.56	6.56	6.56 ± 0.01
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	0.1	
PB	<0.06	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	3.4	3.7	3.5	3.5 ± 0.3
SN	<0.06	<0.06	<0.06	
SR	0.0471	0.0474	0.047	0.0472 ± 0.0004
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	0.006	<0.005	

Nonvianuk	(mg/L)	(mg/L)	(mg/L)	Mean ± C.I. *
AG	<0.008	<0.008	<0.008	
AL	<0.05	<0.05	<0.05	
AS	<0.1	<0.1	<0.1	
B	<0.02	<0.02	<0.02	
BA	0.0022	0.0018	0.0023	0.0021 ± 0.0005
BE	<0.0002	<0.0002	<0.0002	
BI	0.05	<0.04	<0.04	
CA	4.64	4.52	4.56	4.57 ± 0.12
CD	<0.007	<0.007	<0.007	
CO	<0.01	<0.01	<0.01	
CR	<0.04	<0.04	<0.04	
CU	<0.007	<0.007	<0.007	
FE	<0.006	<0.006	<0.006	
K	<1.	<1.	<1.	
W	0.03	<0.03	<0.03	
LI	<0.004	<0.004	<0.004	
MG	0.587	0.571	0.577	0.578 ± 0.016
MN	0.002	0.002	0.001	0.002 ± 0.001
MO	<0.01	<0.01	<0.01	
NA	1.6	1.5	1.6	1.6 ± 0.1
NI	<0.03	<0.03	<0.03	
P	<0.1	<0.1	<0.1	
PB	<0.06	<0.06	<0.06	
SB	<0.09	<0.09	<0.09	
SE	<0.1	<0.1	<0.1	
SI	1.4	1.4	1.4	1.4 ± 0
SN	<0.06	<0.06	<0.06	
SR	0.016	0.015	0.016	0.016 0.001
TI	<0.003	<0.003	<0.003	
TL	<0.2	<0.2	<0.2	
V	<0.006	<0.006	<0.006	
ZN	<0.005	<0.005	<0.005	

Appendix C

Table C1. Stream ion balances, 1990, Katmai National Park and Preserve.

	American Cr.		Battle 1		Battle 2	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	35.4	0.58	0.0	0.00	0.0	0.00
Cl	6.8	0.19	9.4	0.26	7.4	0.21
SO_4	2.5	0.05	18.3	0.38	6.0	0.13
Total anions:		0.82		0.65		0.33
Ca	7.93	0.40	6.57	0.33	2	0.1
Mg	1.76	0.144	2.570	0.211	0.348	0.029
K	<0.5	0	0	0	0	0
Na	3.28	0.14	2.24	0.1	1.50	0.07
Total cations:		0.68		0.64		0.19
Ion sum:		1.50		1.29		0.52

	Battle 3		Battle 4		Battle 5	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	0.0	0.00	5.5	0.09	0.6	0.01
Cl	7.6	0.21	7.5	0.21	8.0	0.23
SO_4	3.7	0.08	4.7	0.10	17.7	0.37
Total anions:		0.29		0.40		0.60
Ca	2.1	0.11	1.85	0.09	10.95	0.55
Mg	0.262	0.021	0.190	0.016	1.80	0.15
K	<0.5	0	<0.4	0	0	0
Na	1.4	0.1	0.96	0.04	2.20	0.10
Total cations:		0.19		0.15		0.79
Ion sum:		0.48		0.55		1.39

	Battle R.		Brooks 2		Brooks 3	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	5.4	0.09	64.1	1.05	30.4	0.50
Cl	8.2	0.23	7.4	0.21	9.7	0.27
SO_4	6.7	0.14	8.3	0.17	22.0	0.46
Total anions:		0.46		1.43		1.23
Ca	4.04	0.20	24.3	1.22	9.72	0.49
Mg	0.753	0.062	3.77	0.309	1.81	0.15
K	<0.4	0	1.1	0.03	<0.5	0
Na	1.74	0.08	6.23	0.3	3.48	0.15
Total cations:		0.34		1.82		0.79
Ion sum:		0.80		3.25		2.02

Table C1.Continued.

	Brooks 4		Brooks 5		Brooks 6	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	34.2	0.56	45.1	0.74	37.6	0.62
Cl	4.7	0.13	4.1	0.12	5.2	0.15
SO_4	12.3	0.26	6.3	0.13	1.0	0.02
Total anions:		0.95		0.99		0.78
Ca	8.70	0.44	19.3	0.97	12.50	0.63
Mg	2.65	0.22	3.30	0.27	2.89	0.24
K	0.9	0.02	0	0	0	0
Na	3.95	0.17	5.29	0.23	4.17	0.18
Total cations:		0.85		1.47		1.04
Ion sum:		1.80		2.46		1.82

	Brooks 7		Brooks R.		Margot Cr.	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	70.3	1.15	27.0	0.44	32.3	0.53
Cl	8.0	0.23	5.8	0.16	5.6	0.16
SO_4	4.7	0.10	6.0	0.13	13.0	0.27
Total anions:		1.48		0.73		0.96
Ca	19.7	0.99	8.1	0.40	14.2	0.71
Mg	2.70	0.22	2.06	0.169	2.02	0.17
K	<0.4	0	0.7	0.02	<0.5	0
Na	4.75	0.21	3.79	0.2	3.35	0.15
Total cations:		1.41		0.76		1.02
Ion sum:		2.89		1.49		1.98

	Nonvianuk R.		Savonoski R.		Ukak R.	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	12.9	0.21	31.7	0.52	50.5	0.83
Cl	5.8	0.16	7.7	0.22	26.8	0.75
SO_4	3.7	0.08	25.0	0.52	70.0	1.46
Total anions:		0.45		1.26		3.04
Ca	4.60	0.23	21.0	1.05	32.60	1.63
Mg	0.651	0.053	4.92	0.40	8.00	0.66
K	<0.4	0	1.2	0.03	2.2	0.06
Na	1.7	0.07	4.34	0.2	24.3	1.06
Total cations:		0.36		1.67		3.40
Ion sum:		0.81		2.93		6.44

Table C2. Stream ion balances, 1991, Katmai National Park (inlets to Brooks Lake).

	West Cr.		Up-a-Tree Cr.		Hidden Cr.	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	45.8	0.75	57.0	0.93	51.7	0.85
Cl	0	0	5.4	0.15	7.4	0.21
SO_4	0.0	0	16.0	0.33	0.0	0.00
Total anions:		0.75		1.42		1.06
Ca	11.0	0.55	16.4	0.82	12.2	0.6
Mg	2.63	0.216	2.73	0.22	2.57	0.21
K	0.5	0.01	0.95	0.02	1.1	0.03
Na	3.92	0.17	4.51	0.20	4.10	0.18
Total cations:		0.95		1.26		1.03
Ion sum:		1.70		2.68		2.09

	One-shot Cr.		Headwater Cr.	
	mg/L	meq/L	mg/L	meq/L
HCO_3	38.9	0.64	35.6	0.58
Cl	9.6	0.27	4.0	0.11
SO_4	0.0	0.00	0.0	0.00
Total anions:		0.91		0.70
Ca	9.6	0.48	7.8	0.39
Mg	1.79	0.15	2.44	0.20
K	0.82	0.02	0.82	0.02
Na	3.37	0.1	4.02	0.17
Total cations:		0.79		0.79
Ion sum:		1.70		1.49

Table C3. Stream anions, 1992, Katmai National Park (inlets to Brooks Lake).

	West Cr.		Up-a-Tree Cr.		Hidden Cr.	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	58.1	0.95	67.5	1.11	42.7	0.70
Cl	3.0	0.1	2.2	0.06	2.7	0.08
SO_4	0.3	0.03	15.0	0.31	0.0	0.00
Total anions:		1.04		1.48		0.78

	One Shot Cr.		Headwater Cr.		Cat *	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
HCO_3	35.3	0.58	42.6	0.70	37.7	0.62
Cl	1.8	0.05	2.3	0.06	2.0	0.06
SO_4	0.0	0.00	0.0	0.00	19.3	0.40
Total anions:		0.63		0.76		1.08

* SO_4 data an average of three widely disparate trials: 50, 8, and 0 mg/L

Appendix D

American Creek

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.13	0.22	0.18
AS :	<0.04	<0.05	
B :	<0.03	<0.03	
BA :	0.0034	0.0041	0.0038
BE :	<0.0006	<0.0005	
BI :	<0.04	<0.04	
CA :	7.76	8.09	7.93
CD :	<0.003	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.40	0.46	0.43
K :	<0.5	<0.4	
LI :	<0.002	<0.002	
MG :	1.72	1.80	1.76
MN :	0.026	0.028	0.027
MO :	<0.005	<0.006	
NA :	3.27	3.28	3.28
NI :	<0.01	<0.02	
P :	<0.2	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.08	<0.07	
SI :	5.5	6.07	5.79
SN :	<0.05	<0.04	
SR :	0.029	0.03	0.03
TI :	0.0097	0.011	0.010
TL :	<0.08	<0.06	
V :	<0.004	<0.003	
ZN :	<0.003	0.005	

Battle River

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.09	0.07	0.08
AS :	<0.05	<0.05	
B :	<0.03	<0.03	
BA :	0.0039	0.0036	0.0038
BE :	<0.0005	<0.0005	
BI :	<0.04	<0.04	
CA :	4	4.08	4.04
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.03	0.083	0.06
K :	<0.4	<0.4	
LI :	<0.002	<0.002	
MG :	0.753	0.753	0.753
MN :	0.021	0.021	0.021
MO :	<0.006	<0.006	
NA :	1.76	1.71	1.74
NI :	<0.02	<0.02	
P :	<0.1	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	2.21	2.21	2.21
SN :	<0.04	<0.04	
SR :	0.015	0.015	0.015
TI :	<0.002	<0.002	
TL :	<0.06	<0.06	
V :	<0.003	<0.003	
ZN :	0.055	0.014	

Battle #1			
	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	3.85	3.82	3.84
AS :	<0.05	<0.05	
B :	<0.03	<0.03	
BA :	0.0094	0.011	0.0102
BE :	0.0006	<0.0005	
BI :	<0.04	<0.04	
CA :	6.45	6.69	6.57
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.22	0.21	0.22
K :	<0.4	0.6	
LI :	<0.002	<0.002	
MG :	2.51	2.62	2.57
MN :	0.083	0.085	0.084
MO :	<0.006	<0.006	
NA :	2.27	2.2	2.24
NI :	<0.02	<0.02	
P :	<0.1	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	5.45	5.55	5.50
SN :	<0.04	<0.04	
SR :	0.031	0.031	0.031
TI :	<0.002	<0.002	
TL :	<0.06	<0.06	
V :	<0.003	<0.003	
ZN :	0.014	0.025	

Battle #2			
	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.2	0.2	0.2
AS :	<0.05	<0.05	
B :	<0.03	<0.03	
BA :	0.005	0.0045	0.0048
BE :	<0.0005	<0.0005	
BI :	<0.04	<0.04	
CA :	2	2	2
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.16	0.18	0.17
K :	0.4	<0.4	
LI :	<0.002	<0.002	
MG :	0.356	0.34	0.348
MN :	0.019	0.017	0.018
MO :	<0.006	<0.006	
NA :	1.58	1.42	1.50
NI :	<0.02	<0.02	
P :	<0.1	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	2.65	2.37	2.51
SN :	<0.04	<0.04	
SR :	0.0087	0.0082	0.0085
TI :	<0.002	<0.002	
TL :	<0.06	<0.06	
V :	<0.003	<0.003	
ZN :	0.007	0.056	

Battle #3

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.16	0.03	0.10
AS :	<0.04	<0.05	
B :	<0.03	<0.03	
BA :	0.0039	0.0041	0.0040
BE :	<0.0006	<0.0005	
BI :	<0.04	<0.04	
CA :	2.1	2.1	2.1
CD :	<0.003	0.009	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	0.003	<0.003	
FE :	0.12	0.14	0.13
K :	<0.5	<0.4	
LI :	<0.002	<0.002	
MG :	0.259	0.264	0.262
MN :	0.004	0.004	0.004
MO :	<0.005	<0.006	
NA :	1.4	1.4	1.4
NI :	<0.01	<0.02	
P :	<0.2	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.08	<0.07	
SI :	1.41	1.4	1.41
SN :	<0.05	<0.04	
SR :	0.0073	0.0069	0.0071
TI :	<0.003	<0.002	
TL :	<0.08	<0.06	
V :	<0.004	<0.003	
ZN :	<0.003	0.02	

Battle #4

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.04	0.05	0.05
AS :	<0.05	<0.05	
B :	<0.03	<0.03	
BA :	0.0009	0.001	0.001
BE :	<0.0005	<0.0005	
BI :	<0.04	<0.04	
CA :	1.9	1.8	1.85
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	0.003	<0.003	
FE :	0.049	<0.01	
K :	<0.4	<0.4	
LI :	<0.002	<0.002	
MG :	0.191	0.188	0.190
MN :	<0.002	<0.002	
MO :	<0.006	<0.006	
NA :	0.93	0.98	0.96
NI :	<0.02	<0.02	
P :	<0.1	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	2.14	2.19	2.17
SN :	<0.04	<0.04	
SR :	0.0062	0.0056	0.0059
TI :	<0.002	0.002	
TL :	<0.06	<0.06	
V :	<0.003	<0.003	
ZN :	0.029	0.015	

Battle #5

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.16	0.15	0.16
AS :	<0.05	<0.05	
B :	<0.03	<0.03	
BA :	0.0048	0.0074	0.0061
BE :	<0.0005	<0.0005	
BI :	<0.04	<0.04	
CA :	10.6	11.3	10.95
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.02	0.035	0.03
K :	<0.4	0.6	
LI :	<0.002	<0.002	
MG :	1.76	1.84	1.8
MN :	0.017	0.015	0.016
MO :	<0.006	<0.006	
NA :	2.2	2.19	2.20
NI :	<0.02	<0.02	
P :	<0.1	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	3.94	3.98	3.96
SN :	<0.04	<0.04	
SR :	0.043	0.044	0.044
TI :	<0.002	<0.002	
TL :	<0.06	<0.06	
V :	<0.003	<0.003	
ZN :	0.004	0.021	

Brooks River

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.16	<0.03	
AS :	<0.04	<0.04	
B :	<0.03	<0.03	
BA :	0.0021	0.0021	0.0021
BE :	<0.0006	<0.0006	
BI :	<0.04	<0.04	
CA :	7.89	8.24	8.07
CD :	<0.003	<0.003	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.065	0.084	0.075
K :	0.8	0.6	0.7
LI :	<0.002	<0.002	
MG :	2.01	2.1	2.06
MN :	0.005	0.003	0.004
MO :	<0.005	<0.005	
NA :	3.64	3.94	3.79
NI :	<0.01	<0.01	
P :	<0.2	<0.2	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.08	<0.08	
SI :	4.45	4.69	4.57
SN :	<0.05	<0.05	
SR :	0.028	0.03	0.029
TI :	<0.003	<0.003	
TL :	<0.08	<0.08	
V :	<0.004	<0.004	
ZN :	<0.003	<0.003	

Brooks #2			
	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.06	0.05	0.06
AS :	<0.05	<0.05	
B :	<0.03	<0.03	
BA :	0.0049	0.0049	0.0049
BE :	<0.0005	<0.0005	
BI :	<0.04	<0.04	
CA :	23.6	24.9	24.3
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.28	0.28	0.28
K :	1.3	0.9	1.1
LI :	<0.002	<0.002	
MG :	3.67	3.87	3.77
MN :	0.019	0.02	0.02
MO :	<0.006	<0.006	
NA :	6.04	6.41	6.23
NI :	<0.02	<0.02	
P :	<0.1	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	9.09	9.27	9.18
SN :	<0.04	<0.04	
SR :	0.0656	0.0684	0.067
TI :	0.003	<0.002	
TL :	<0.06	<0.06	
V :	<0.003	<0.003	
ZN :	0.005	0.16	

Brooks #3			
	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	<0.03	0.06	
AS :	<0.04	<0.05	
B :	<0.03	<0.03	
BA :	0.0044	0.0049	0.0047
BE :	<0.0006	<0.0005	
BI :	<0.04	<0.04	
CA :	9.46	9.98	9.72
CD :	<0.003	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.28	0.29	0.29
K :	<0.5	0.5	
LI :	<0.002	<0.002	
MG :	1.76	1.85	1.81
MN :	0.018	0.019	0.019
MO :	<0.005	<0.006	
NA :	3.53	3.43	3.48
NI :	<0.01	<0.02	
P :	<0.2	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.08	<0.07	
SI :	8.11	8.11	8.11
SN :	<0.05	<0.04	
SR :	0.037	0.036	0.037
TI :	<0.003	0.004	
TL :	<0.08	<0.06	
V :	<0.004	<0.003	
ZN :	0.016	0.027	

Brooks #4

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.2	0.19	0.2
AS :	<0.05	<0.05	
B :	<0.03	<0.03	
BA :	0.0043	0.0044	0.0044
BE :	<0.0005	<0.0005	
BI :	<0.04	<0.04	
CA :	8.71	8.68	8.70
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.57	0.56	0.57
K :	0.8	1	0.9
LI :	<0.002	<0.002	
MG :	2.66	2.63	2.65
MN :	0.04	0.047	0.044
MO :	<0.006	<0.006	
NA :	3.99	3.9	3.95
NI :	<0.02	<0.02	
P :	<0.1	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	8.84	8.78	8.81
SN :	<0.04	<0.04	
SR :	0.033	0.032	0.033
TI :	0.01	0.0091	0.01
TL :	<0.06	<0.06	
V :	<0.003	<0.003	
ZN :	0.007	0.015	0.011

Brooks #5

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.11	<0.03	
AS :	<0.05	<0.04	
B :	<0.03	<0.03	
BA :	0.0053	0.0051	0.0052
BE :	<0.0005	<0.0006	
BI :	<0.04	<0.04	
CA :	19.8	18.8	19.3
CD :	<0.004	<0.003	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.85	0.92	0.89
K :	0.8	<0.5	
LI :	<0.002	<0.002	
MG :	3.36	3.2	3.3
MN :	0.067	0.063	0.065
MO :	<0.006	<0.005	
NA :	5.22	5.35	5.29
NI :	<0.02	<0.01	
P :	<0.1	<0.2	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.08	
SI :	8.19	7.98	8.09
SN :	<0.04	<0.05	
SR :	0.0762	0.0776	0.0769
TI :	0.004	0.003	0.004
TL :	<0.06	<0.08	
V :	<0.003	<0.004	
ZN :	0.005	<0.003	

Brooks #6

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.03	0.06	0.05
AS :	<0.04	<0.05	
B :	<0.03	<0.03	
BA :	0.005	0.005	0.005
BE :	<0.0006	<0.0005	
BI :	<0.04	<0.04	
CA :	12.4	12.6	12.5
CD :	<0.003	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.65	0.62	0.64
K :	<0.5	0.5	
LI :	<0.002	<0.002	
MG :	2.86	2.91	2.89
MN :	0.041	0.04	0.04
MO :	<0.005	<0.006	
NA :	4.18	4.15	4.17
NI :	<0.01	<0.02	
P :	<0.2	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.08	<0.07	
SI :	5.17	5.26	5.22
SN :	<0.05	<0.04	
SR :	0.0562	0.0556	0.0559
TI :	0.003	<0.002	
TL :	<0.08	<0.06	
V :	<0.004	<0.003	
ZN :	0.05	0.006	

Brooks #7

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.05	<0.03	
AS :	<0.05	<0.04	
B :	<0.03	<0.03	
BA :	0.0083	0.008	0.0082
BE :	<0.0005	<0.0006	
BI :	<0.04	<0.04	
CA :	20.1	19.3	19.7
CD :	<0.004	<0.003	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.98	0.96	0.97
K :	<0.4	<0.5	
LI :	<0.002	<0.002	
MG :	2.74	2.66	2.7
MN :	0.059	0.057	0.058
MO :	<0.006	<0.005	
NA :	4.63	4.86	4.75
NI :	<0.02	<0.01	
P :	<0.1	<0.2	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.08	
SI :	6.3	6.36	6.33
SN :	<0.04	<0.05	
SR :	0.0896	0.0921	0.0909
TI :	<0.002	<0.003	
TL :	<0.06	<0.08	
V :	<0.003	<0.004	
ZN :	0.019	0.012	0.016

Margot Creek

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	0.14	0.13	0.14
AS :	<0.04	<0.04	
B :	<0.03	<0.03	
BA :	0.0023	0.0024	0.0024
BE :	<0.0006	<0.0006	
BI :	<0.04	<0.04	
CA :	14.3	14	14.2
CD :	<0.003	<0.003	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.28	0.28	0.28
K :	<0.5	<0.5	
LI :	<0.002	<0.002	
MG :	2.03	2	2.02
MN :	0.012	0.013	0.013
MO :	<0.005	<0.005	
NA :	3.34	3.35	3.35
NI :	<0.01	<0.01	
P :	<0.2	<0.2	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.08	<0.08	
SI :	6.28	6.29	6.29
SN :	<0.05	<0.05	
SR :	0.038	0.038	0.038
TI :	0.012	0.01	0.011
TL :	<0.08	<0.08	
V :	<0.004	<0.004	
ZN :	<0.003	<0.003	

Nonvianuk River

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	<0.03	0.11	
AS :	<0.04	<0.05	
B :	<0.03	<0.03	
BA :	0.0031	0.0037	0.0034
BE :	<0.0006	<0.0005	
BI :	<0.04	<0.04	
CA :	4.59	4.6	4.6
CD :	<0.003	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	<0.003	<0.003	
FE :	0.14	0.086	0.11
K :	<0.5	<0.4	
LI :	<0.002	<0.002	
MG :	0.648	0.653	0.651
MN :	0.0084	0.011	0.010
MO :	<0.005	<0.006	
NA :	1.7	1.6	1.7
NI :	<0.01	<0.02	
P :	<0.2	<0.1	
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.08	<0.07	
SI :	1.71	1.81	1.76
SN :	<0.05	<0.04	
SR :	0.016	0.016	0.016
TI :	<0.003	0.003	
TL :	<0.08	<0.06	
V :	<0.004	<0.003	
ZN :	<0.003	0.006	

Savonoski River

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	6.95	7.93	7.44
AS :	<0.05	<0.04	
B :	<0.03	<0.03	
BA :	0.039	0.046	0.043
BE :	<0.0005	<0.0006	
BI :	<0.04	<0.04	
CA :	21.3	20.7	21.0
CD :	<0.004	<0.003	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	0.007	0.012	0.010
FE :	8.39	9.32	8.86
K :	1.3	1	1.2
LI :	0.007	0.0085	0.008
MG :	4.86	4.97	4.92
MN :	0.15	0.15	0.15
MO :	<0.006	<0.005	
NA :	4.13	4.55	4.34
NI :	<0.02	<0.01	
P :	0.2	0.2	0.2
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.08	
SI :	14.2	16.3	15.3
SN :	<0.04	<0.05	
SR :	0.0748	0.0793	0.0771
TI :	0.254	0.365	0.310
TL :	<0.06	<0.08	
V :	0.015	0.02	0.02
ZN :	0.045	0.02	

Ukak River

	(mg/L)	(mg/L)	Mean
AG :	<0.01	<0.01	
AL :	6.27	9.07	7.67
AS :	<0.05	<0.05	
B :	0.17	0.17	0.17
BA :	0.029	0.042	0.036
BE :	<0.0005	<0.0005	
BI :	<0.04	<0.04	
CA :	32	33.2	32.6
CD :	<0.004	<0.004	
CO :	<0.01	<0.01	
CR :	<0.01	<0.01	
CU :	0.0093	0.013	0.011
FE :	6.25	8.04	7.15
K :	2	2.4	2.2
LI :	0.067	0.067	0.067
MG :	7.8	8.21	8.0
MN :	0.11	0.13	0.12
MO :	<0.006	<0.007	
NA :	24.2	24.4	24.3
NI :	<0.02	<0.02	
P :	0.3	0.3	0.3
PB :	<0.04	<0.04	
SB :	<0.04	<0.04	
SE :	<0.07	<0.07	
SI :	15.3	26.2	20.8
SN :	<0.04	<0.04	
SR :	0.0939	0.1	0.0970
TI :	0.224	0.425	0.325
TL :	<0.06	<0.06	
V :	0.012	0.017	0.015
ZN :	0.017	0.027	

Up-a-tree Ck.	(mg/L)	(mg/L)	(mg/L)	Mean C.I.*
AG :	< 0.01	< 0.01	< 0.01	
AL :	0.96	0.92	1.20	1.03 ± 0.38
AS :	< 0.04	< 0.04	< 0.04	
B :	0.02	0.02	< 0.02	0.01 ± 0.03
BA :	0.0093	0.0086	0.0099	0.0093 ± 0.0016
BE :	< 0	< 0	< 0	
BI :	< 0.04	< 0.04	< 0.04	
CA :	17.0	16.0	16.2	16.4 ± 1.3
CD :	< 0.002	< 0.002	< 0.003	
CO :	< 0.01	< 0.01	< 0.01	
CR :	< 0.01	< 0.01	< 0.01	
CU :	< 0.002	0.002	0.002	0.001 ± 0.003
FE :	1.66	1.55	1.92	1.71 ± 0.48
K :	0.84	0.90	1.10	0.95 ± 0.34
W :	< 0.01	< 0.01	< 0.02	
LI :	< 0.002	< 0.002	< 0.002	
MG :	2.80	2.67	2.72	2.73 ± 0.16
MN :	0.058	0.051	0.055	0.055 ± 0.009
MO :	< 0.005	< 0.005	< 0.005	
NA :	4.61	4.38	4.55	4.51 ± 0.30
NI :	< 0.01	< 0.01	< 0.01	
P :	0.1	0.1	0.1	0.1 ± 0.0
PB :	< 0.04	< 0.04	< 0.04	
SB :	< 0.04	< 0.04	< 0.04	
SE :	< 0.04	< 0.04	< 0.05	
SI :	8.77	8.42	9.03	8.74 ± 0.77
SN :	< 0.04	< 0.04	< 0.04	
SR :	0.0496	0.0480	0.0497	0.049 ± 0.002
TI :	0.063	0.057	0.080	0.067 ± 0.030
TL :	< 0.04	< 0.04	< 0.08	
V :	0.004	0.005	0.005	0.005 ± 0.001
ZN :	0.0059	< 0.002	< 0.002	

Headwater	(mg/L)	(mg/L)	(mg/L)	Mean C.I.*
AG :	< 0.01	< 0.01	< 0.01	
AL :	0.31	0.47	0.36	0.38 ± 0.20
AS :	< 0.04	< 0.04	< 0.04	
B :	< 0.02	< 0.02	< 0.02	
BA :	0.0049	0.0061	0.0055	0.0055 ± 0.0015
BE :	< 0	< 0	< 0	
BI :	< 0.04	< 0.04	< 0.04	
CA :	7.7	8.0	7.6	7.8 ± 0.5
CD :	< 0.002	< 0.002	< 0.002	
CO :	< 0.01	< 0.01	< 0.01	
CR :	< 0.01	< 0.01	< 0.01	
CU :	< 0.002	0.004	< 0.002	
FE :	0.716	0.906	0.760	0.794 ± 0.249
K :	0.68	0.96	0.82	0.82 ± 0.35
W :	< 0.01	< 0.01	< 0.01	
LI :	< 0.002	< 0.002	< 0.002	
MG :	2.41	2.51	2.39	2.44 ± 0.16
MN :	0.036	0.041	0.036	0.038 ± 0.007
MO :	< 0.005	< 0.005	< 0.005	
NA :	4.04	4.06	3.97	4.02 ± 0.12
NI :	< 0.01	< 0.01	< 0.01	
P :	< 0.09	0.09	< 0.09	
PB :	< 0.04	< 0.04	< 0.04	
SB :	< 0.04	< 0.04	< 0.04	
SE :	< 0.04	< 0.04	< 0.04	
SI :	8.33	8.88	8.41	8.54 ± 0.74
SN :	< 0.04	< 0.04	< 0.04	
SR :	0.029	0.030	0.029	0.029 ± 0.001
TI :	0.019	0.031	0.021	0.024 ± 0.016
TL :	< 0.04	< 0.04	< 0.04	
V :	< 0.003	< 0.003	< 0.003	
ZN :	< 0.002	0.003	0.002	0.002 ± 0.004

*95% confidence intervals of mean

West Ck.	(mg/L)	(mg/L)	(mg/L)	Mean C.I.*
AG :	< 0.01	< 0.01	< 0.01	
AL :	< 0.02	< 0.02	< 0.02	
AS :	< 0.04	< 0.04	< 0.04	
B :	< 0.02	< 0.02	< 0.02	
BA :	0.0036	0.0037	0.0036	0.0036 ± 0.0001
BE :	< 0	< 0	< 0	
BI :	< 0.04	< 0.04	< 0.04	
CA :	11.0	11.0	11.0	11.0 ± 0.0
CD :	< 0.002	< 0.002	< 0.002	
CO :	< 0.01	< 0.01	< 0.01	
CR :	< 0.01	< 0.01	< 0.01	
CU :	< 0.002	< 0.002	< 0.002	
FE :	0.31	0.31	0.31	0.31 ± 0.00
K :	0.50	0.59	0.40	0.50 ± 0.24
W :	< 0.01	< 0.01	< 0.01	
LI :	< 0.002	< 0.002	< 0.002	
MG :	2.62	2.66	2.61	2.63 ± 0.07
MN :	0.025	0.023	0.023	0.024 ± 0.003
MO :	< 0.005	< 0.005	< 0.005	
NA :	3.93	3.96	3.88	3.92 ± 0.10
NI :	< 0.01	< 0.01	< 0.01	
P :	< 0.09	< 0.09	< 0.09	
PB :	< 0.04	< 0.04	< 0.04	
SB :	< 0.04	< 0.04	< 0.04	
SE :	< 0.04	< 0.04	< 0.04	
SI :	5.06	5.15	5.00	5.07 ± 0.19
SN :	< 0.04	< 0.04	< 0.04	
SR :	0.0500	0.0502	0.0490	0.0497 ± 0.0016
TI :	< 0.002	< 0.002	< 0.002	
TL :	< 0.04	< 0.04	< 0.04	
V :	< 0.003	< 0.003	< 0.003	
ZN :	< 0.002	< 0.002	< 0.002	

Hidden Ck.	(mg/L)	(mg/L)	(mg/L)	Mean C.I.*
AG :	< 0.01	< 0.01	< 0.01	
AL :	0.12	0.12	0.13	0.12 ± 0.01
AS :	< 0.04	< 0.04	< 0.04	
B :	< 0.02	< 0.02	< 0.02	
BA :	0.0035	0.0036	0.0033	0.0035 ± 0.0004
BE :	< 0	< 0	< 0	
BI :	< 0.04	< 0.04	< 0.04	
CA :	12.0	12.4	12.1	12.2 ± 0.5
CD :	< 0.002	< 0.003	< 0..00	
CO :	< 0.01	< 0.01	< 0.01	
CR :	< 0.01	< 0.01	< 0.01	
CU :	0.003	< 0.002	< 0.002	
FE :	0.43	0.42	0.44	0.43 ± 0.02
K :	1.2	1.1	1.1	1.1 ± 0.1
W :	< 0.01	< 0.02	< 0.02	
LI :	< 0.002	< 0.002	< 0.002	
MG :	2.60	2.58	2.53	2.57 ± 0.09
MN :	0.020	0.019	0.018	0.019 ± 0.003
MO :	< 0.005	< 0.005	< 0.005	
NA :	4.02	4.18	4.09	4.10 ± 0.20
NI :	< 0.01	< 0.01	< 0.01	
P :	< 0.09	< 0.09	< 0.09	
PB :	< 0.04	< 0.04	< 0.04	
SB :	< 0.04	< 0.04	< 0.04	
SE :	< 0.04	< 0.05	< 0.05	
SI :	8.39	8.44	8.43	8.42 ± 0.07
SN :	< 0.04	< 0.04	< 0.04	
SR :	0.032	0.033	0.032	0.032 ± 0.001
TI :	0.0075	0.0073	0.0075	0.0074 ± 0.0003
TL :	< 0.04	< 0.08	< 0.08	
V :	< 0.003	< 0.003	< 0.003	
ZN :	< 0.002	< 0.002	< 0.002	

*95% confidence intervals of mean

One Shot Ck.	(mg/L)	(mg/L)	(mg/L)	Mean C.I.*
AG :	< 0.01	< 0.01	< 0.01	
AL :	0.57	0.55	0.59	0.57 ± 0.05
AS :	< 0.04	< 0.04	< 0.04	
B :	< 0.02	< 0.02	< 0.02	
BA :	0.0075	0.0076	0.0075	0.0075 ± 0.0001
BE :	< 0	< 0	0.0005	
BI :	< 0.04	< 0.04	< 0.04	
CA :	9.73	9.27	9.78	9.59 ± 0.70
CD :	< 0.003	< 0.003	< 0.003	
CO :	< 0.01	< 0.01	< 0.01	
CR :	< 0.01	< 0.01	< 0.01	
CU :	< 0.002	< 0.002	< 0.002	
FE :	0.811	0.803	0.816	0.810 ± 0.016
K :	0.88	0.70	0.89	0.82 ± 0.27
W :	< 0.02	< 0.02	< 0.02	
LI :	< 0.002	< 0.002	< 0.002	
MG :	1.81	1.73	1.82	1.79 ± 0.12
MN :	0.028	0.029	0.029	0.029 ± 0.001
MO :	< 0.005	< 0.005	< 0.005	
NA :	3.44	3.27	3.41	3.37 ± 0.23
NI :	< 0.01	< 0.01	< 0.01	
P :	< 0.09	< 0.09	< 0.09	
PB :	< 0.04	< 0.04	< 0.04	
SB :	< 0.04	< 0.04	< 0.04	
SE :	< 0.05	< 0.05	< 0.05	
SI :	8.09	7.61	7.87	7.86 ± 0.60
SN :	< 0.04	< 0.04	< 0.04	
SR :	0.037	0.035	0.037	0.036 ± 0.003
TI :	0.033	0.030	0.033	0.032 ± 0.004
TL :	< 0.08	< 0.08	< 0.08	
V :	< 0.003	< 0.003	< 0.003	
ZN :	0.003	< 0.002	0.003	0.003 ± 0.001

*95% confidence intervals of mean

Kulik#8	(mg/L)	[Hot spring stream inlet]
AG	<0.008	
AL	0.22	
AS	<0.1	
B	<0.02	
BA	0.0075	
BE	<0.0002	
BI	<0.04	
CA	69.1	
CD	<0.007	
CO	<0.01	
CR	<0.04	
CU	0.01	
FE	0.1	
K	<1. 1.	
W	<0.03	
LI	<0.004	
MG	6.15	
MN	0.032	
MO	<0.01	
NA	4.7	
NI	<0.03	
P	<0.1	
PB	0.07	
SB	<0.09	
SE	<0.1	
SI	5.52	
SN	<0.06	
SR	0.242	
TI	0.003	
TL	<0.2	
V	<0.006	
ZN	0.005	

Appendix E

Appendix E

Table E. Light and associated characteristics, 1990-1992, lakes of Katmai National Park and Preserve.

Lake	K_d (PAR) (m^{-1})			Secchi Depth (m)			Depth of 1% Light (m)		
	1990	1991	1992	1990	1991	1992	1990	1991	1992
Battle	0.081	0.057	0.073	18	18	16	56	81	63
Brooks	0.164	0.250	0.183	9.8	9.6	9.6	28	18	25
Coville	0.274	0.260	0.349	6.0	4.9	6.2	17	18	13
Grosvenor	0.179	0.200	0.219	12	7.8	11	26	23	21
Hammersly	—	0.188	0.128	—	12	16	—	24	36
Idavain	0.411	—	—	4.4	—	—	11	—	—
Kukaklek	0.178	0.103	0.151	16	11	12	26	45	30
Kulik	0.148	0.146	0.135	12	8.3	11	31	32	34
Murray	0.108	0.183	0.177	16	10	14	43	25	26
Naknek	0.156	0.288	0.186	6.5	3.2	6.2	29	16	25
Nonvianuk	0.129	0.144	0.202	14	9.0	11	36	32	23

Lake	Phytoplankton (mg/m^{-3} chl. *a*)			Apparent Color (Pt-Co Units)			Turbidity (NTU)		
	1990	1991	1992	1990	1991	1992	1990	1991	1992
Battle	0.16	—	0.09	3	≤1	0	0.40	0.40	1.7
Brooks	0.37	—	0.57	5	0	7	0.51	0.40	2.3
Coville	0.56	—	1.75	17	0	4	0.83	1.0	1.7
Grosvenor	0.45	—	0.59	0	0	6	0.62	0.6	1.4
Hammersly	—	—	0.55	—	0	3	—	0.4	2.7
Idavain	1.02	—	—	0	—	—	0.77	—	—
Kukaklek	0.28	—	0.97	10	0	≤1	0.44	0.50	1.1
Kulik	0.34	—	0.58	0	0	≤1	0.46	0.50	1.7
Murray	0.23	—	0.46	0	0	11	0.29	0.50	1.2
Naknek	0.50	—	0.88	13	≤10	33	0.81	1.3	1.8
Nonvianuk	0.30	—	0.68	0	0	5	0.61	0.40	1.5